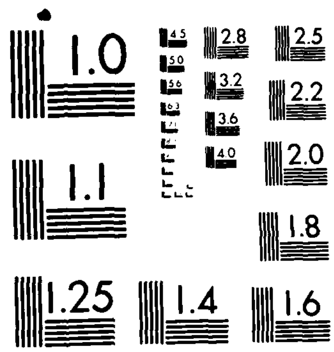
AD-A162 283 EVALUATION OF SPARING MODELS FOR A MISSILE SYSTEM(U) 1/2
AIR FORCE INST OF TECH WRIGHT-PATTERSON AFB OH SCHOOL
OF SYSTEMS AND LOGISTICS L A GREENE SEP 85
UNCLASSIFIED AFIT/GSM/LSY/85S-15 F/G 14/1 NL



MICROCOPY RESOLUTION TEST CHART
NATIONAL BUREAU OF STANDARDS-1963-A

EVALUATION OF SPARING MODELS FOR A MISSILE SYSTEM

THESIS

Lloyd A. Greene
Captain, USAF

AFIT/GSM/LSY/85S-15

DEPARTMENT OF THE AIR FORCE
AIR UNIVERSITY
AIR FORCE INSTITUTE OF TECHNOLOGY

Wright-Patterson Air Force Base, Ohio

AFIT/GSM/LSY/85S-15

EVALUATION OF SPARING MODELS FOR A MISSILE SYSTEM

THESIS

Lloyd A. Greene
Captain, USAF

AFIT/GSM/LSY/85S-15

The contents of the document are technically accurate, and no sensitive items, detrimental ideas, or deleterious information are contained therein. Furthermore, the views expressed in the document are those of the author(s) and do not necessarily reflect the views of the School of Systems and Logistics, the Air University, the United States Air Force, or the Department of Defense.

A-1

AFIT/GSM/LSY/85S-15

EVALUATION OF SPARING MODELS FOR A MISSILE SYSTEM

THESIS

Presented to the Faculty of the School of Logistics

of the Air Force Institute of Technology

Air University

In Partial Fulfillment of the

Requirements for the Degree of

Master of Science in Systems Management

Lloyd A. Greene Jr., B.S.

Captain, USAF

September 1985

Acknowledgements

I am indebted to Lieutenant Colonel Jeffrey J. Phillips of the Air Force Institute of Technology for his professional guidance and assistance during the research process. Sincere appreciation is also extended to Mr. Johnny Wilson and Mr. Jim Kerr for their tutledge of the concepts of the spare parts alocation process. These people were generous sharing both their time and expertise facilitating my research task, and without their help my job would have been impossibe given the time constraints.

Most importantly, I want to thank my wife Jeanine. During this project, she has been a friend, a typist, a reader, and a companion. She endured the hardships from working many late nights with me, and I thank her from my heart.

Lloyd Greene

<u>Table of Contents</u>

List of Figures

List of Tables

Abstract

This study investigated pipeline spares calculation with four life Cycle cost models for the Maverick Missile System. The research goal was to evaluate any differences in the pipeline costs that were calculated by the Hughes Cost of Ownership Model, the Maverick Life Cycle Cost Model, and the Modified METRIC Maverick Model, and a variation of the Modified METRIC Maverick.

The analysis was accomplished by identifying the independent variables with a Factor Analysis. A Factorial Design of three factors and five levels was used to develop the observations that were used by the life Cycle costs models to calculate pipeline costs. The relative effect that each of the independent variables had upon the pipeline costs was evaluated by an Analysis of Variance. Differences in life Cycle cost models pipeline costs were determined by Tukey's procedure. The results indicated that costs produced by the Hughes Cost of Ownership Model and the Modified MOD-METRIC Maverick calculated equal pipeline costs, but the Maverick Life Cycle Cost Model and the MOD-METRIC Maverick did not compute costs equal to any other life Cycle cost model. The independent variables of Mean time Between Failure and the Depot Cycle Time had the most effect upon each of the life cycle costs models pipeline costs.

I. Introduction

Problem Statement

Today, spare parts comprise a significant percentage of the investment dollars in weapons systems acquisitions. The justifications for these procurements are receiving increased scrutiny in order to achieve the most efficient operations and to maintain adequate inventory stock levels. The initial requirements for spare parts procurements are calculated by Life Cycle Cost models, which are used to predict cost during a future time period. The model development process is often based upon a subjective series of tests which should convince decision makers of a model's predictive credibility (15:29). According to Banks (1:14), these tests should be an iterative procedure that is repeated until the model's accuracy is judged acceptable for the user's needs.

A new spare parts algorithm was developed for The Maverick Life Cycle Cost Model. A quantifiable process should be developed to evaluate these life cycle cost models. The methodology should provide a thorough comparison and evaluation of the new model with the old version in the area of historical spare parts costs.

Background

The Hughes Aircraft Company was the only producer of the Maverick M'ssile. Contractually, they were required to perform a Life Cycle Cost Analysis for all design modifications to the Maverick Missile. Hughes uses a proprietary Life Cycle Cost Model that is called the Hughes Cost of Ownership Model (HCOM). A second source, The Raytheon Missile System Division, will also produce the Maverick; However, Raytheon does not have a Life Cycle Cost model that can be easily adapted for the Maverick analysis.

The Air Force is required to make an independent verification of costs pertaining to program modifications submitted by different Maverick contractors. Initially, these costs were computed by a general purpose avionics life cycle cost model, the LCC Model, an accounting life cycle cost analysis program developed during the early 1970's. To comply with Air Force requirements, a specific cost model, called the Maverick Missile Life Cycle Cost Model (MAVLCC), was developed. The program was written in FORTRAN 77 and designed to operate with the VAX 11/780 computer system. The spare parts calculation in MAVLCC is of primary concern because it is the most critical determinant of operating and maintenance cost in the modeling environment.

Since the development of the original LCC cost model, several algorithms have been designed to provide a more detailed evaluation of the spare parts calculation for a

missile. Random failures were identified by the Munitions Design Trade/Operation and Support Cost Model (MONMOD), an accounting LCC model developed for the AMRAAM Missile. MONMOD's major advantage is that it assumes that the operational missiles fail randomly. Mod-Metrics, developed for the Air Force during the 1960's, incorporates the improvements of MONMOD and assumes that missiles are stored both at depot and bases. However, Mod-Metric calculations assume steady state conditions during the model scenario. A new model, Dyna-Metric extends the Mod-Metric approach and allows environmental conditions to change during the life cycle.

Justification

Often analysts and decision makers are skeptical of the results from computer models. Their fears may result from a general unfamiliarity with the system or a lack of confidence in the model's calculations. A primary goal of the model developer during a validation should be to help the users to develop confidence in the model and to increase the credibility of the model to an acceptable level, so that the model will be used by managers and other decision makers" (1:388).

The calculations that perform the initial spares calculation in MAVLCC have been significantly modified during three major revisions. Although these modifications should provide more accurate cost estimates, it is important

to identify the relationships with the original model and establish the model's capabilities. Following this process, managerial confidence in the model's predictive capability and productivity should increase, leading to a more accurate and timely understanding of initial spare parts acquisitions.

Scope

The purpose of this study is to analyze computer algorithms that perform initial spare computations to calculate the cost of spare parts to fill voids in the logistic pipeline. Each model will be used to calculate the cost of the spare parts (dependent variable) that is based on the same set of initial conditions (independent variables). The evaluation process inspected the internal and external functions of the models. Internally, each model was inspected to determine its methodology of computing spares. The external evaluation was based on a sensitivity analysis of the models' performances in calculating initial spares.

Research Objectives

The goal of this study was to evaluate different algorithms that are capable of determining initial spare parts costs for a missile system. Each model was used to compute an initial spares cost for several different operational scenarios, and then the different model outputs

were compared to each other. The relative similarities or differences provided information concerning the sensitivity of the different models to the same input conditions. Selected samples were chosen out of the population of independent variable values and used to calculate the pipeline costs.

There are three objectives of this research, which are based on the calculation of pipeline costs. First, the primary objective was to determine if there are significant differences among the models' performances. The internal structure of the models will be analyzed based on the methodology used for calculation, and the external structure will be analyzed based on the models output of pipeline costs. The second objective was to determine the effect that each treatment in the sensitivity analysis will have upon the model's ability to compute pipeline spare parts. The third objective studied the significant interactions of the different treatments, because the treatments may be interacting with each other causing effects that are greater than the sum of the individual treatments.

The delineation of tasks to complete the research is:

1. Identify the algorithms that can determine the spare parts requirement for the Maverick Missile. The algorithms must be substantially developed to provide rapid generation of Maverick costs.

2. Identify the significant variables that are to be used for the input conditions. Although a totally inclusive list is not reasonable, the number of variables should be large enough to provide an experimental variation for analysis.
3. Perform the sensitivity analysis with the different models for each of the different input conditions.
4. Analyze the models internally and externally to determine significant differences.
5. Analyze each model's output to determine the effect each treatment has upon the model's predictive capabilities.

II. Literature Review

Introduction

The literature review is divided into three sections. The first part presents a review of the process for evaluating simulation models; the second part reviews the experimental procedures that were used to optimize the experimentation; and the third section describes the models that were used for the analysis, the Hughes Cost of Ownership Model (HCOM), the MOD-METRIC Maverick Life Cycle Cost Model (MAVMOD), and the Maverick Life Cycle Cost Model (MAVLCC). Although much of the literature states that there is no exact method for evaluating simulation models, this thesis methodology is largely dependent upon the viewpoints of Dr. Robert Shannon, a pioneer in the field of simulation analysis.

Definitions

A life cycle cost model is only a simulation of the actual environment. However, it must contain appropriate input variables and assumptions in order to successfully compute different engineering change proposals. The prediction of a model's capabilities is determined by an evaluation process, which does not contain any set procedures; however, the model evaluation process should be based on the insights about the projected model performance

(18:248). A primary goal of model comparisons with the actual system should provide an appropriate amount of information to build an acceptable level of confidence that its inferences will represent the actual system.

The evaluation process should prove that the model performs the instructions correctly and that these instructions accurately simulate the real world environment. Although a particular test may reject a model's credibility, most often model evaluations require a series of tests that provide information about system performance. These tests are divided into a verification and validation processes. Verification tests evaluate the model's computations, while validation tests examine the model's output relative to the system or a standard.

Previous Research

The Maverick Life Cycle cost model had not previously been subjected to a validation process. An inquiry into the development process indicated that this step was not contractually specified, nor was there any documentation concerning an informal evaluation process. A review of the literature yielded that that a validation process had been performed (2) for a similar spare parts inquiry, which examined the input-output process of two models that computed stock requirements for repairable secondary items. The researchers' summary was that their methodology only allowed comparison of models under specific controlled

conditions, and the primary benefit of this type of research is that a large data base is not required (2:5-4).

Background of Sources

The methodology and design of this simulation analysis research are patterned from the readings of Dr. Robert Shannon, Dr. Jerry Banks, and Dr. John Carson II. They are recognized as experts in the fields of computer simulation and statistical analysis. This section provides a brief and summary the academic and professional expertise that these gentlemen have provided in the field of simulation and analysis.

1. Robert Shannon received his Ph.D. from Oklahoma State University in 1965. Currently, he is a Professor at the University of Alabama in Huntsville. His fields of research interest include Operations Research, Systems Analysis, Statistics, Systems Simulation, Management Control Systems, and Decision Theory. Dr. Shannon has published over 40 research papers in scientific journals. He is a Registered Professional Engineer in the State of Alabama; a member of Alpha Pi Mu, Sigma Xi, American Institute of Industrial Engineering, American Society of Engineering Education, Operations Research Society of America, and The Institute of Management Sciences.

2. Jerry Banks received his Ph.D. from Oklahoma State University. Currently, he is an Associate Professor at the School of Industrial and Systems Engineering, Georgia

Institute of Technology. He has taught simulation for many years and consults to numerous industrial and governmental agencies. He has published Procurement and Inventory Systems, Reighold, 1967; Procurement and Inventory Ordering Tables, Pergamon, 1977. He is a member of the Operations Research Society of America and the American Institute of Industrial Engineering. He was the General Chairman of the Winter Simulation Conference during 1983.

3. John S. Carson, II received his Ph.D. in Operations Research from the University of Wisconsin-Madison. Currently, he is an Assistant Professor at the School of Industrial and Systems Engineering, Georgia Institute of Technology. He has published research articles in Operations Research and SIAM Journal on Computing. He is a member of the Institute of Management Science and the Operations Research Society of America.

Verification Process

The verification process is concerned with the inner workings of the model. The primary intent is to make sure that the algorithm accurately represents the conceptual assumptions. Shannon's definition of verification is "to insure that the model behaves as required (15:210)." Banks claims that the verification process is similar to the steps that a computer programmer should use for "debugging" any program. His steps for verification are:

1. Have the code checked by another programmer.

2. Develop a computer flow diagram.

3. Have the code print out a wide variety of statistics.

4. Check the independent variables.

5. Make the computer code self explanatory.

Validation Process

This section reviews several methods which can be used to validate models. However, each of the validation processes may be subjective. Van Horn (18:248) states that there is no such thing as an "appropriate validation process", and each model must be validated upon a set of specific insights that are peculiar to that system. The importance of the validation process is that it should increase the acceptance level of the model, so that it will be used by decision makers. Thus, the goal is to demonstrate that the model truly represents the behavior of the actual system, thereby allowing the model to be used as a substitute for the purposes of experimentation or evaluation or both (1:376). There are three generic determinations during the validation phase the authors (1;5;12;15) suggest should follow:

1. Face Value Validity.
2. Model Assumptions Validity.
3. Comparison of the Model with the Real World.

Face Value Validity. The face value of a model is primarily concerned that the model appears reasonable to

experts, who are knowledgeable with the actual system and can correlate between the model and the real world. A goal during this inspection should reveal that there is a correct manipulation of the independent variables. Shannon (15:215) said that it is important for the model's inner structure to be composed of essential building blocks necessary for a correct system emulation.

A Sensitivity Analysis is an objective test, which is used to check a model's face validity. The goal of a sensitivity analysis is to confirm that the model's computations provide changes in the correct direction. Banks (1:385) claims that this process is easy for several input parameters, but as the number of input parameters increases, the task also becomes more difficult, which requires selections for the more critical input parameters.

Validation the Model Assumptions. A second stage for testing the internal structure, this validation examines the model's structural assumptions and data assumptions. The analysis of the structure is concerned that simplifications and abstractions, which were drawn from the real world have been correctly implemented in the model (1:385). Shannon notes that models may be deficient because they include irrelevant or exclude relevant variables.

The analysis of the input data structure examines both the source and the representation of the input variables (1:386;15:218). Banks and Shannon (1:385;15:218) suggest

that the reliability of the data should be verified by observation or experimentation whenever practical. Also, it is important to check the methods that were used if statistical tests have been performed on raw data in generating the input variables.

Validation of the Input-Output Transformations. The goal of the transformation's validation is to demonstrate that the model can successfully predict events in the future. Banks recommends the use of at least two data bases: the first for calibrating the model and the second for validating the model. Then a T-Test or a Turing Test can be used to compare the different systems.

Law warns (9:376) that classical statistical tests based on independent and normally distributed observations are not directly applicable, because simulations are often autocorrelated and may have multicollinearity problems. Also, because the model is an approximation, hypothesis testing may only indicate significant differences between the results.

A subjective test was developed by A.M. Turing, which evaluates the reasonability of the model's results. The Turing Test requires people who are knowledgeable about the system to differentiate between output from a model's simulation and those of the real system. The different outputs must contain the same information, which should be exactly in the same format. If systems experts succeed in

discriminating the data, then deficiencies with the model can be found and corrected (1:401). Although this is a subjective process, the Turing test can approximate a scientific process with the introduction of several sets of data (15:29). The literature suggests that this is a widely used test, because of the lack of statistical assumptions, and the credibility that the experts can add to the model (15:29,229;1:401).

Summary

The primary goal of any evaluation should be to develop confidence in a model, so that insights into the actual system's operation and performance may be acquired. However, Shannon (15:236) points out:

> if these insights contradict our current knowledge with the system, [then] they are suspect and should be examined carefully before we accept them... By far the most important test [should answer the question], does it make sense [15:236-237].

For an optimum validation process, Shannon (15) lists several criteria that should be followed:

1. Use common sense and logic.
2. Take maximum advantage of the knowledge and insight of those most familiar with the system under study
3. Conduct appropriate statistical testing of all assumptions and hypotheses possible.
4. Check the model building process.
5. Confirm that the model performs as required.
6. Compare the input-output transformations of the model and the real world system, using statistical and Turing tests.
7. Perform field tests or research where possible.
8. Perform a sensitivity analysis on the input variables.
9. Check the predictions for accuracy.

III. Research Methodology

Background

The primary objective of the research project is to determine if there are statistically significant differences between each of the different life cycle cost (LCC) model's computations for initial spares to fill the logistics pipeline; these are called pipeline spares. The costs for pipeline spares, the dependent variable, will be generated at different factor levels for each LCC model; the Maverick Life Cycle Cost Model (MAVLCC), the Mod-Metric version of the Maverick Life Cycle Cost Model (MAVMOD), an updated version of the Maverick Life Cycle Cost Model (MAVMOD-A), and the Hughes Cost of Ownership Model (HCOM). The secondary objective is to determine the effect of the factor levels for each of the models. Each of the factor levels represent an ordered combination of the independent variables depot cycle time (DEPOT), the number of Flying Hours (FLYING), and the mean time between failure (MTBF). The tertiary research objective examines the effect of interactions among the independent variables. Practically defined, an interaction occurs when the mean responses for two levels of a factor A is different for different levels of factor B (13:561).

The experiment was designed to evaluate the pipeline costs computed by each life cycle cost model by Tukey's

procedure for multiple comparison. The experimental design provided for an Analysis of Variance (ANOVA) among the factor levels. The selection of the number of observations was made as a compromise between statistical considerations and experimental practicality. A desirable scenario during ANOVA is to have a large number of observations, so that effects of one single observation will be minimal. Authors (4;13;1) recommend having more than 30 observations, with the goal to obtain the largest amount of samples that are economically feasible. Constraints in this study reside with the AFIT computer system, both in manpower and operational time. A smaller data base facilitates data processing with a desk top computer and decreases computational time with the VAX 11/780 and Cyber. In a similar experiment, Blake (2) reduced the number of experiments to study only first and second order effects of the permutated data matrix. The experimenters reasoned that a lack of understanding with the high order effects could become difficult to interpret and reduced experiments were more manageable. This reduced the number of experiments from a possible of 6561 (3^8) to 243. Blake reported:

> The study team decided that the interpretation of high order interactions becomes very complex intuitively and is of very little use. Therefore, the experiment was fractionated to produce main effects and two-way interaction effects only. This also reduced the number of data points required to 243, which was a much more manageable figure [This figure was reduced from 6,561] [2:6].

Introduction

The Research Methodology describes the experimental approach that was necessary to compute the pipeline costs for the experiment. The chapter has been divided into sections explaining topics used for the development of this research that include: Experimental Design, LCC Model Description, Factor Analysis, Factorial Design, and Data Generation.

The Experimental Design provides a overview of the research process; justifying the methodology for identification of independent variable and selection of the Analysis of Variance technique, which is used to analyze the relationships between the experimental data. Finally, an overview of the Maverick Missile System is provided, explaining terminology that will be used throughout this thesis. The LCC Model Description section discusses the four LCC models that are used in the study. The LCC models are the Hughes Cost of Ownership Model, The Maverick Life Cycle Cost Model, The MOD-METRIC Maverick, and a Modified version of the MOD-METRIC Maverick. A description has been provided for each LCC model (except for the Modified MOD-METRIC, for which only the modification is provided) including an overview, background, LCC model assumptions, and a listing of calculations that are used to compute the pipeline costs. The independent variables (depot cycle time, number of flying hours, and mean time between failure)

were selected by a Factor Analysis, a program in the Statistical Package for the Statistical Sciences (SPSS). The factor procedure describes the identification of the principal components that are used to compute the number of failed parts in the MOD-METRIC algorithm. The Factorial Design identified the number of observations (125) necessary for an optimum experiment. The minimization process determined the number of observations necessary to evaluate differences between the LCC models and factor levels. Finally, in the Data Generation section, a description is provided of the structural changes in each LCC model that were required to generate the pipeline costs (dependent variable) for each of the LCC models.

Experimental Design

The goal of experimental design is to decide which variables to simulate so that the desired information may be obtained with the least cost of experimental time. A generalized procedure is to initially vary many variables, and later target those that have a significant impact. Law described an algorithm to follow during simulation analysis:

> [Experimental Design] is particularly useful in the early stage of experimentation when we are pretty much in the dark about which factors are important and how they might affect the response. As we learn more about the behavior of a model, we may want to move on and become more precise in our goals [9:371].

Factorial Designs

Factorial designs are experimental strategies which can reduce the experimentation for a project with several or many factors. If there is only one factor, then the process is simply to experiment for a number of levels. However, a complete simulation of ten factors at four levels would require 10,000 different experiments! A 2^k factorial design can be used for a small number of factors.

A 2^k Factorial design requires two levels for each factor. Then the simulation would be run at each of the levels, and the number of experiments for ten levels would be:

$$2^{10} = 1024 \text{ experiments.}$$

Analysis Technique

A single factor ANOVA was the statistical method used to test for non-equality of the LCC model's calculation for pipeline costs. Evaluation of relative differences between the LCC model's pipeline costs was computed by Tukey's procedure. ANOVA is a general technique that is robust to experimental assumptions of the input data; in contrast, a regression analysis is a more specific technique that requires specific relationships between the independent and dependent variables. Both of the techniques require the dependent variable to be quantitative, but ANOVA differs in two respects. First, the independent variables may be qualitative, describing factors such as sex, location, or

group (13:420). Second, there are no assumptions made about any of the statistical relationships between the independent variables. When both ANOVA and Regression fit the assumptions, Neter and Wasserman (13:420-421) recommend that an ANOVA first be employed to determine the effects of the independent variables upon the dependent variables, and followed by a regression technique to determine the quantitative relationships.

The independent variables (qualitative) are the set of LCC model input conditions, the number of flying hours, depot cycle time, and the mean time between failure. Given these input conditions, each LCC model will calculate the cost of initial spare parts to fill the logistics pipeline. This is called pipeline spares. The pipeline costs computed by each LCC model is the dependent variable.

The Maverick System

The Life Cycle Cost Models for the Maverick System calculate the system costs by two different methods. First, the cost is grouped into categories composed of the three related sub-systems, called Contract End Items (CEI). Second, the CEI's are further divided into Line Replaceable Units (LRU) and Shop Replaceable Units (SRU). The three CEI's are:

1. The operational Missile (AGM-65).
2. The training Missile (TGM).
3. The aircraft support structure (launcher).

The Maverick Missile is an air launched, rocket-motor powered air-to-ground (AGM-65) tactical system. The missile consists of a warhead, a propulsion section, and a guidance and control assembly. Although Air Force requirements may change, current plans are to procure approximately 59,000 AGM's during the 10-year acquisition (17:6-33).

The Training Guided Missile (TGM-65) simulates the AGM-65 for air crew training purposes. Physically, the TGM is similar to the AGM in size, weight distribution, and component location; however, the TGM lacks external control surfaces. Approximately 800 TGM's will be purchased through the first 5 years of the program.

The launcher is the mechanical and electrical interface between the Maverick Missile and the aircraft pylon. Although procured with the Maverick System, launcher costs are not normally considered with Maverick engineering change plans (ECP). Provisions have been made with the MAVLCC model to ignore the effects of launcher costs, which was done in this study.

Both the operational and training missile contain subassemblies. All of the assemblies that can be repaired locally are called line replaceable units (LRU), while shop replaceable units are removed and repaired at the Depot. The Maverick Life Cycle Cost Models and the Hughes Cost of Ownership Model are capable of presenting cost information

in each of the different categories. This chapter describes the different LCC models

LCC Model Descriptions

There are four LCC models that this study evaluated for a sensitivity analysis. All of these LCC models are "accounting" models that add inputs from a data file, and perform calculations resulting in output variables. The first LCC model, the original Maverick Life Cycle Cost Model (MAVLCC), will be the standard against which all others will be judged. The second LCC model, called MAVMOD, is a derivative of the MAVLCC that was written by the Analytic Sciences Corp. The "MAV" refers to the Maverick Life Cycle Cost Model and the "MOD" because the subroutine which computes spare parts is base on the Mod-metrics, which is an optimization technique for spare parts allocation (16). The third LCC model, the Hughes Cost of Ownership Model (HCOM), is a proprietary program of Hughes Aircraft. The fourth LCC model, MAVMOD-A, is a modification of the Anser's MAVMOD model designed to illustrate the effect of eliminating a depot spare supply. This change makes the MAVMOD-A model similar with the other LCC models based on the logistical environment assumptions. The following sections provide an overview, background, LCC model assumptions, and the input-output variables available for the Maverick Life Cycle Cost Model (MAVLCC), the Analytic Sciences updated model

(MAVMOD), the update to the MAVMOD model, and the Hughes Cost of Ownership model (HCOM).

Maverick Life Cycle Cost Model

MAVLCC Overview. The Maverick Life Cycle cost model was designed to provide cost of ownership estimates for the infrared version (AGM-65D) of the Maverick Missile. However, it also has the capability of calculating cost for all of the other versions of the Maverick Missile. The LCC model is designed to provide a "top-level" and "detailed level" of life cycle cost elements (17:2-3). The top level categories are equipment, management, support equipment, training , data, and maintenance. The MAVLCC program is written in FORTRAN 77 and is designed to operate on a VAX 11/780 series computer, which uses the Virtual Memory Operating System (17:3). The entire program, including data and output data files, require approximately 1600 kilobytes of text memory.

MAVLCC Background. The Maverick Life Cycle Cost Analysis System was originally developed in 1973 and installed on the Air Force Logistics Command (AFLC) Create Time Share Computer System. The LCC model was later modified by Ultrasystems Defense & Space Systems, Inc. The major purpose of the modification was to make the program "user friendly" and to facilitate engineering change orders. This revision was delivered to the Maverick System Project

Office (SPO) June 15, 1984, and that is the LCC model that is currently in operation for the Maverick missile.

MAVLCC Assumptions. There are five assumptions concerning the operating concept and internal computations of the LCC model:

1. The MAVLCC model assumes that the parts fail deterministically (on a regular time basis).
2. The MAVLCC model system is at steady state.
3. There is a centralized source of material supply, which prevents cannibalization of parts plus lateral transfer among bases or sites.

Input Data Requirements. Data used for the MAVLCC program has been divided into two sections, constants and variables. Constants are data that remain stable throughout the program cycle. An example of a constant would be the number of duty hours in a month (AVGMOGHR), which is stable at 730.5 hours each month (30.5 days). Variables are allowed to change during the program, but they do not necessarily have to change. For example, the number of missiles in the inventory increases to approximately 59,000; however, the depot cycle time remains constant at 1.5 months.

The constants for the MAVLCC program are contained in subroutine MAV17, and the variables are initialized in subroutine MAV4. Appendix C lists the constants and variables modified for this research. The source of data for input into the MAVLCC model is Air Force Logistics Command

Regulation 173-10 "AFLC Cost and Planning Factors" (3). Maverick specific information was provided by Maverick personnel in February 1985.

Model Calculations. This section describes the methodology by which the Maverick Life Cycle Cost Model (MAVLCC) calculates pipeline spare parts cost. The pipeline equation is used to compute the value of hardware shipped from the base to the depot for repair and the return trip to the base cost. The pipeline costs are calculated for Line Replaceable Units (LRU) only, and based on the cost associated with the peak demand month (greatest spares requirement, called DP2) during the life cycle, the component price (UC), and the depot turn time (DCRT) that includes both the depot cycle and two-way transportation times. The pipeline variable costs in MAVLCC are contained in the XTRAVAR(2) array. This computation is contained in the subroutine MAV2, which performs the MAVLCC cost calculations:

XTRAVAR(2) = DP2 * UC(I) * DCRT(I)

where:

DP2 = The peak demand during the 120 month life cycle

UC(I) = Unit cost of the Line Replaceable Unit

DCRT(I) = Depot turnaround time, which includes both the depot cycle time and the two-way transportation.

The monthly demands are represented by the variable DPM in MAVLCC. These demands are the sum of demands during operational usage (FAILS(1,I,J)), the alert demands (FAILS(2,I,J)), and the inventory demands (FAILS(3,I,J)) for the tactical missile (TGM), training missile (AGM), and the launcher assembly.

DPM = FAILS(1,J,K) + FAILS(2,J,K) + FAILS(3,J,K)

Where:

FAILS = The number of failures

J = LRU component

K = month

Where the operational failures are calculated by:

FAILS(I,J,K) = XMN(I,J,K) / XM(I,J)

and:

XMN(I,J,K) = Monthly hours of usage

XM(I,J) = component mean time between failure

Output Variables. MAVLCC prints a listing for the replacement spares for each line replaceable unit (LRU) in an output file called "DEMFAIL.OUT" (17:7). The report is called the "Demand/Failure Summary," which depicts the number of each LRU during the 10 year life cycle. The variable "DMDS(N,J)" contains the value of the LRU where (17:9-51):

N = The number of LRU
J = The year for the requirement

Model Structure. The MAVLCC program contains 20 subroutines. The original FORTRAN code was written in 1973,

and the latest revision (2.0) contains modifications that were completed in June 1984. The subroutine listing in Table 1 (taken from the MAVLCC User's Manual) shows the function of the twenty subroutines (17:4-1).

TABLE 1

Maverick Subroutine Listing

Routine	Function
MAVMAIN	Main program to calculate the Life Cycle Cost of the Maverick
MAV1	Performs model calculations
MAV2	Output cost reports
MAV3	Output usage/demand/support reports
MAV4	Initialization routines
MAV5	Initialization routines
MAV6	Prints input data
MAV7	User Query for constant change
MAV8	User Query for output file generation
MAV9	Saves input data
MAV10	Reads data from file
MAV11	Change variables
MAV12	Change variables
MAV13	User Query for variable change
MAV14	User Query for date changes
MAV15	User Query for variable change (LRU)
MAV16	User Query for variable change (SRU)
MAV17	Initializes constants
MAV18	User Query for output file generation
MAV19	Inflation, production, and R&D costs
MAV20	Main menu

Maverick MOD-METRIC Model

MAVMOD Overview. The MAVMOD program contains a multi-echelon inventory stockage subroutine, which calculates the required number of initial spare parts based on an optimization process. This subroutine was incorporated into the Maverick Life Cycle Cost Model

(MAVLCC) program. The MAVMOD and MAVLCC programs externally appear similar because they both use the same independent variables and format, but their different methods of calculating spare parts produce statistically significantly different results. The objective of the optimization process is to minimize the total number of required spare parts based on a backorder objective. A backorder exists when there is unsatisfied demand for a spare part (12:3). The MOD-METRIC algorithm adds approximately 30 kilobytes of text memory to the MAVLCC program, and each data record requires an additional 2.03 clock minutes plus 1.9 seconds of computer system time on the AFIT VAX 11/780.

MAVMOD Background. The MAVMOD subroutine for spares parts calculation was originally designed for the LCC-2A Life Cycle Cost Model, which is a Life Cycle Cost (LCC) model that is used to evaluate avionics systems. The foundation of the LCC-2A is based on the "Modified Multi Echelon Technique for Recoverable Item Control (MOD-METRIC), which was developed by John A. Muckstadt and Craig C. Sherbourne of the Rand Corporation. The METRIC model was designed for the Air Force for use in determining appropriate base and depot inventory levels for recoverable items; those items that are typically expensive and experience low demand rates (11:1). METRIC can be used to perform three types of stock level analyses. The first method of operation is optimization, the METRIC model is

used to determine the base and depot stock levels so that the availability of spare parts in the pipeline is maximized. Second, the METRIC model may be used to redistribute existing amounts of stock between the bases and depot. The objective is to find the base and depot stock levels that maximize the availability. Third, the METRIC model may be used to evaluate the performance or investment of a stock allocation between the depot and bases (11:1-2;16:123). The current modified METRIC subroutine was encoded (from the LCC-2A model) by The Analytical Sciences Corporation for incorporation into the Maverick Life Cycle Cost Model (MAVLCC).

MAVMOD Assumptions. There are five assumptions concerning the operating concept and internal computations of the model:

1. The MAVMOD model assumes that the parts fail stocastically by a Poisson distribution.
2. The MAVMOD model computes spares based on a total system backorder objective.
3. The system is at steady state, and the analysis is for that specific environment only (a snapshot in time).
4. There is a centralized source of material supply, which prevents cannibalization of parts plus lateral transfer among bases or sites.

5. The MOD-METRIC subroutine will maximize the availability of spare parts.

Input Data Requirements. The Analytic Sciences model (MAVMOD) requires all of the same data as the Maverick Life Cycle Cost Model, and additional data for computation of the Modified Metric (MOD-METRIC) spares subroutine calculation. Primarily, the additional data is required to provide failure rates that are dependent upon the number of bases; the MAVLCC program computes spares based on failures per system. The number of bases and the number of missiles at each base are additional data required for the MOD-METRIC program. Also, the MOD-METRIC subroutine requires the pipeline transportation time to be divided into three parts: the time from the base to depot, the depot cycle time, and the re-supply time back to the base. The source for the pipeline times is Air Force Logistics Command Regulation 173-10 "AFLC Cost and Planning factors" (3). The constants for the MOD-METRIC subroutine are contained in the subroutine MAV17 and summarized in TABLE 2.

Model Calculations. This section describes the methodology by which the Modified Maverick Life Cycle Cost Model (MAVMOD) calculates pipeline spare parts cost. The discussion describes both the linkages with the Maverick Life Cycle cost model and the separate calculations of the modified METRIC (MOD-METRIC) subroutine. A primary concern of the linkage from MAVLCC to MAVMOD is the translation of

TABLE 2

Spares Input Data

RSTC	=216	Conus transportation time, Hours
RSTO	=288	Overseas transportation time, Hours
DRC1	=540	Depot repair cycle time, Hours
DSSF	=0.0	Depot safety stock factor
ANBC	=1	Number conus bases stocking AGMS
ANBO	=7	Number of overseas bases stocking AGMS
TNBC	=41	Number of conus bases stocking TGMS
TNBO	=18	Number of overseas bases stocking TGMS

demand from system failures to base failures per month. An assumption was made that the parts fail at a same rate throughout each of the bases. Thus, after determining the system failure rates based on peak monthly demands, base failures can be determined by multiplying the total number of failures multiplied by the percentage of missiles located at each base. The conversion from system to base failures is performed by the following FORTRAN statements in subroutine MAV1:

for AGM's

```
AFAIL(I,J) = PEAKDEM(AGM) * APERCENT(J)
```

where:

AFAIL = Number of AGM failures

I = Line Replaceable Unit (LRU) identifier

J = Base identifier

PEAKDEM = Monthly peak demand for AGM's

APERCENT = Percent of tactical missiles at base J for TGM's

TFAIL(I,J) = PEAKDEM(TGM) * APERCENT(J)

where:

TFAIL = Number of TGM failures

I = Line Replaceable Unit (LRU) identifier

J = Base identifier

PEAKDEM = Monthly peak demand for TGM's

APERCENT = Percent of training missiles at base J

The MOD-METRIC Algorithm. The goal of this application of the modified METRIC approach is to optimize the availability of spares based on having zero backorders at each location. A backorder exist at a point in time when there is unsatisfied demand for an item (12:3). There are three basic calculations that are performed in determining this optimal allocation. First, the number of depot spares are calculated based on the demand from the base failure data. Second, the number of base spares are calculated. Third, for both the depot and base spare calculations a marginal analysis is used to optimize the availability of spares.

The Depot Spare Calculation. The depot spares are calculated in the subroutine "DSPARE". The demand for spare

parts exerted at the depot is calculated by determining the repair cycle time (the round trip transportation from base to depot plus the depot repair time) and multiplying by the total number of failures for each line or shop replaceable unit. A safety factor was added to the depot stock that accounts for random variations in the demand. The safety stock for this experiment was set to zero for this experiment because there are not comparable calculations in the other LCC models being researched. The FORTRAN statements computing the depot demand are:

```
NSS(I) = DLAMBDA(I) * DT(I) + DSSC
```

The demand (DLAMBDA) is calculated by the system failures (SFAILS), which were determined by the main program, in addition a factor UFP was used that accounts for the fraction of components removed at the depot that will be unverified failures.

```
DLAMBDA(I) = SFAILS(I) * (1 / 730) / (1 - UFP(I))
```

where:

SFAILS(I) = Total number of system failures for component I

730 : Conversion rate from hourly to monthly

UFP(I) = Unverifiable failures

The repair cycle time (DT(I)) is the sum of the round trip transportation from the base to depot, plus the repair time at the depot. The transportation time is determined by

calculating an average time value based on the percentage of bases located in the conus and overseas.

$$DT(I) = DRC + (BDSC * PERCONUS) + (BDSO * PEROVER)$$

where:

DRC = Depot repair time

BDSC = Transportation time for conus bases to depot

PERCONUS = The percentage of bases in conus

BDSO = Transportation time for overseas bases to depot

<u>The Base Spares Calculation</u>. The number of spares required at the base locations are calculated in the subroutine MARGNL (Marginal Analysis by optimization). These calculations are based on an optimization procedure that maximizes the availability of spare parts throughout the system and allocates spare parts on a unit basis to those bases that provide the greatest reduction in backorders. The algorithm is designed to assign zero spare parts to a system, determine the number of backorders that result, and compare the backorder rate with the predetermined availability objective. If the availability objective is satisfied the program records the number of spares and continues the computations; however, failure to meet the availability objective means that one more spare must be added to that base. Then, the comparison of backorder rates and availability continues. Summarizing, the goal of the marginal analysis is to ascertain that a spare part is available at each base when a failure occurs.

Modified Mod-Metrics Model

The MAVMOD-A model is very similar to the MAVMOD, except that the modified version MAVMOD-A does not assign any pipeline spares to the depot location. This change makes assumptions about the logistics environment similar to those for the Maverick Life Cycle Cost Model and Hughes Cost of Ownership model. Only one change was made for the MAVMOD-A change. The subroutine DSPARES, which calculates depot spares was deleted.

Hughes Cost of Ownership Model

HCOM Overview. The Hughes Cost of Ownership Model (HCOM) is a generic logistics cost LCC model that was exercised for Maverick system support cost analysis. The HCOM model is written in FORTRAN 77, and designed to operate on the VAX 11/780 series computer. The entire program, including data files, require approximately 400 kilobytes of storage space. HCOM is designed to perform cost analysis based on base repair, depot repair, or disposal (17:3). This analysis can be performed for different indenture levels-system, subsystem, assembly, or part. The HCOM model also has the capability to perform tradeoff studies for both policy and design changes. The HCOM operation is based on a "top down" design and calculates costs from the "bottom up". The "top" refers to the major assemblies such as the Maverick Missile, while the "bottom" can be described by a lower indenture level item such as the center aft section.

HCOM BACKGROUND. The Hughes Cost of Ownership Model was originally developed with the IBM 370 computer during the early 1970's. The program was modified for the VAX operating system in 1983. The HCOM model was most recently used to perform a support life cycle cost analysis for the Laser Maverick. Permission was granted for educational testing of the spare parts algorithms by the Tucson Maverick Programs Group at Hughes Aircraft Company, Tucson, Arizona.

HCOM Assumptions. The operating concept and computations of the Hughes Cost of Ownership model are based on the same assumptions as the Maverick Life Cycle Cost Models.

1. The HCOM model assumes that the parts fail deterministically.
2. The HCOM model system is at steady state; the operating scenario is constant.
3. There is a centralized source of material supply, which prevents cannibalization of parts and lateral transfer among bases or sites.

Input Data Requirements. The input data for the Hughes Cost of Ownership model are structured in the "top down" fashion. The data can be entered by system, assembly, and component, where the detail of information is general at the top system level and becomes more detailed at the bottom component level. System data contains information describing the logistics environment parameters such as

pipeline time, the number of bases, and labor rates etc. ; component data becomes more specific describing criteria such as failure rates and shipping weights (6:4-1).

The source of data for input into the HCOM model is Air Force Logistics Command Regulation 173-10 "AFLC Cost and Planning Factors" (3). Maverick specific information was provided by Maverick personnel in February 1985. System level data for this study is supplied in Appendix B.

Model Calculations. This section describes the methodology by which HCOM calculates pipeline spare parts costs. The pipeline equation computes the cost of hardware shipped from the base to the depot for repair and the return costs. The pipeline costs equation requires input from the number of maintenance actions (REPGEN), the maintenance actions costs (6) , the total pipeline time for a two-way shipment (TOTPIP); the depot actions for cost of repair parts, conus pipeline for repair parts, and the average number of deployed organizations. The variable for pipeline costs in HCOM is contained in the U(1,2) matrix. This computation is contained in the subroutine EQATN, which performs the HCOM cost calculations:

```
U(1,2) = REPGEN * (   G(2) * 2 * TOTPIP
                    + G(6) * OST(1,NV) * TOTORG/30)
```

where:

REPGEN = The average number of maintenance actions per organization per month

G(2) = Cost of indenture level under analysis

2 = Effect of a two-way shipment

TOTPIP = The total pipeline time

G(6) = Average cost of repair parts

OST(1,NV) = Pipeline delay of repair parts

TOTORG = Total number of organizations

30 = Conversion for a monthly effect

Failure Calculation. The monthly failures are represented by the variable REPGEN in HCOM. These failures are the sum of failures during operational usage (REPGEN1), the non-operational failures (STOCLH), and the items relegated to long term storage (STOFLR).

REPGEN = REPGEN1 + STOCLH + STOFLR

Where the operational failures are calculated by:

REPGEN1 = HRSUSE * G(4) * .01 / G(1) * TOTSYS * QPSYS

Where:

HRSUSE = Number of operational hours

G(4) = Unit probability of failure

.01 = Time conversion factor for MTBF

TOTSYS = Total number of systems

QPSYS = Quantity of units per system

Where the non-operational failures are calculated by:

STOCLH = (730.5 - HRSUSE) * FPCH * TOTSYS * QPSYS

Where:

730.5 = Number of hours in a month

HRSUSE = Hours of system usage-monthly

FPCH = Storage failure rate

TOTSYS = Total number of systems

QPSYS = Quantity of units per system

Where the storage failures are calculated by:

STOFLR = 730.5 * FPCH * TSSTOR * QPSYS

Where:

730.5 = Number of hours in a month

FPCH = Storage failure rate

TSSTOR = Total number of systems in storage

QPSYS = Quantity of units per system

Pipeline Calculation. The Pipeline is defined by the time to fill the pipeline for the overseas and conus bases. The HCOM equation is:

TOTPIP = PIPE(1,NV) * CORG + PIPE(2,NV) * ORG

Where:

PIPE(I,NV) = Pipeline estimate

I = Location (1 = Conus, 2 = Overseas)

CORG = Number of Conus Organizations

ORG = Number of Overseas Organizations

PIPE(I,NV) = Pipeline estimate

I = Location (1 = Conus, 2 = Overseas)

CORG = Number of Conus Organizations

ORG = Number of Overseas Organizations

Factor Analysis

Overview. The variables used for this experimentation were identified by a factor analysis. These variables were later verified by personnel in the Maverick System Project Office. A factor analysis is a statistical technique that can be used to determine basic structures or latent variables among an independent data stream. A primary goal of factor analysis is to reduce the number of variables in an experiment into common groups and provide a name for the groups (14). The factor analysis calculations were performed by the Statistical Package for the Social Sciences (SPSS) using the routine "Factor". The data base for the factor experiment was developed by a FORTRAN subroutine, which is based on the MOD-METRIC approach to spare parts calculation and was later incorporated into the updated Maverick Life Cycle Cost Model (MAVMOD).

The results of the factorial analysis suggest that the significant variables that could be used to determine the number of line replaceable units are the number of facilities, pipeline supply time, and safety stock requirements. A heuristic review of the input variables was done with SPO personnel, and they recommended manipulating the mean time between failure, the number of flying hours, and the depot cycle time. Although only three variables will be kept for this study, the five significant input

variables were prioritized by the factor analysis accordingly:

1. Mean Time Between Failure.
2. Number of Flying Hours.
3. Depot Cycle Time.
4. Number of facilities.
5. Safety Stock Level.

Procedure. The factor analysis performed two functions for data analysis. First, the test was used to rank those variables that are input into the spares model to determine the most significant input variables. Second, factor analysis was used to attempt to reduce the number of independent variables that will require treatment for the four life cycle cost models. The input data base for the factor analysis was generated by the FORTRAN subroutine that calculates spare parts by the Mod-Metric Approach (11), which is the same subroutine in the updated version of the Maverick Life Cycle Cost Model (MAVLCC). There were nine independent variables that were capable of variation for subroutine input, and the output is in both Line Replaceable Units (LRU) and Shop Replaceable Units (SRU). Table 3 summarizes the variables, and was used by SPSS (14) for the factor analysis.

The method of identifying the underlying factors of the data base is called determining the dimensionality in factor analysis. This is accomplished by finding the amount of variation explained by each component of the input data.

TABLE 3

Factor Analysis

Glossary of Variables

SPSS LABEL	ACRONYM	AVG VALUE	DEFINITION
Q1	NRU	1.78	The number of repairable units
Q2	NBC	4.99	Number of Conus bases
Q3	NBO	15.12	Number of Overseas bases
Q4	NIO	286.29	Number of Overseas sites
Q5	RST	382.04	Conus resupply time
Q6	RSTO	720.00	Overseas resupply time
Q7	DMC	284.79	Depot replacement time
Q8	BDSC	382.04	Conus shipping time
Q9	DSSC	1.64	Required safety stock factor
Q10	LRU	6456.20	Dependent requirement
Q11	SRU	11215.63	Dependent requirement

The authors (14:469;8:383) defined three general steps to follow during the factor analysis procedure:

1.) Preparation of a correlation matrix.
2.) Extraction of the initial factors.
3.) Rotation-the search for interpretable factors.

Preparation of the Correlation Matrix. Correlation is a measure of the relationship between two variables identified for analysis. This measure may range from -1 to +1, where the sign indicates the direction in which two variables are statistically related. The absolute magnitude indicates the relative strength, and a "0" indicates a lack of a statistical relationship (4:448). The collection of all of the correlation coefficients between all possible pairs of variables were summarized into a table called a correlation matrix, which is calculated by the sub-program Factor in SPSS.

Extraction of the Initial Factors . The initial factors are determined by the method of Principal-Components Analysis (PCA) , which determines the factors in a way that explains as much of the total variation in the data as possible with a minimum of factors (8:389). The explanation of variation for each manifestation variable can be solved by calculating the eigenvalues in the eigenstructure from the correlation matrix, and by dividing the eigenvalue by the total number of manifestation variables to describe its amount of variation. The SPSS mnemonic used was PA1, principal factoring without iteration.

The eigenvalues were used to rank the significance of the manifestation variables because they indicate the explanation of variation. The following table from an SPSS evaluation indicates the dimensionality of the manifestation variables, the eigenvalues, and the amount of variation explained.

TABLE 4

Dimensionality of the

Manifestaionn Variables

LABEL	EIGENVALUE	PERCENT	DEFINITION
Q2	1.25757	15.7	Number of Repairable Units
Q3	1.212	15.2	Number of Conus Bases
Q4	1.00347	12.5	Number of Overseas Bases
Q5	1.00287	12.5	Number of Overseas Sites
Q6	1.00022	12.5	Conus Resupply Time
Q7	.99347	12.4	Overseas Resupply Time
Q8	.78802	9.9	Conus shipping Time
Q9	.74238	9.3	Required Safety Stock

<u>Rotation of Principal Components</u>. Two heuristic rules of thumb were employed to determine the number of factors that need to be kept for an adequate representation of the manifestation variables. The first rule of thumb is based on the eigenvalue size that retains factors explaining the largest fraction of variance in the manifestation variables. A second rule of thumb is the "scree test", which evaluates the magnitude of the eigenvalues against the number of eigenvalues (10:6-25).

a.) Selection Based on Eigenvalues. The dimensionality of five factors was calculated by SPSS. SPSS's computation was based on a rule of thumb that keeps factors if the corresponding eigenvalues are greater than one.

After increasing the number of factors to 6, there was a significant increase to the communalities which describes the portion of the variation that was explained by that factor. But, when increasing the number of factors to 7, the communalities increased at a decreasing rate. Summarizing, the first five factors would be retained for analysis, but the communalities for six factors suggest that another test should be performed.

b.) The SCREE Test. The eigenvalues were plotted against the number of eigenvalues. The results are shown on Figure 1.

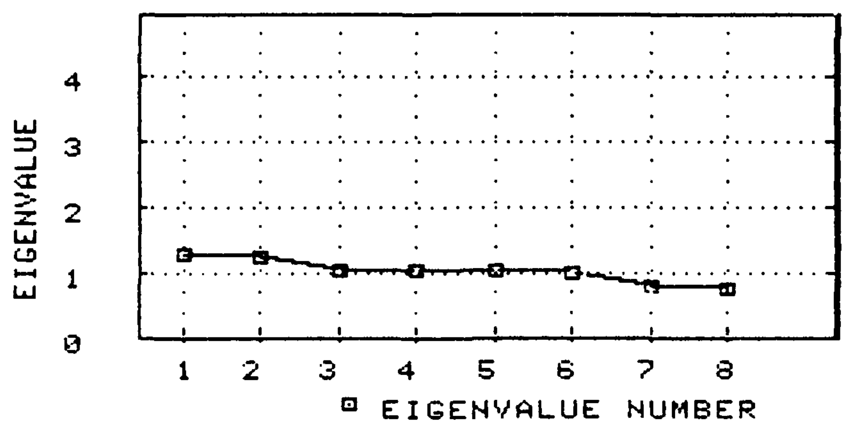


Figure 1. Scree Line

The selection rule states that seven eigenvalues should be kept because a straight line could be drawn through the entire set of data points.

Summary. The Rule of Thumb and the Scree test do suggest similar results, with the actual number of factors to be between 5 and 7. The final selection of independent variables was based from rotation of the principal components. A summary of the test results are shown in TABLE 5.

TABLE 5

Factor Selection Table

Test	Result
Rule of Thumb	Keep the first 5 factors
Scree Test	Keep the first 7 factors

The primary objective of the rotation process, a transformation of the data, is to develop a structure for the input variables such that one factor can be identified as representing a group of variables. There are two axes available for rotating the data; orthogonal when the axes are kept in the same orientation after the rotation, and oblique when the axis are not kept in the same rotation. For this study, an orthogonal rotation was used because the factors resulting from the rotation are uncorrelated (8:394). An analytic rotation process is usually performed rather than a geometric representation when more than two

dimensions are being analyzed (10:6-45). The Varimax Rotation is available in SPSS. McNickols describes the varimax methodology:

> The varimax procedure uses an objective function which tries to simplify the columns in the factor structure by maximizing the variance of the loadings in each column. The usual result is to make each loading either very large or very small. Kaiser normalization refers to a correction in the procedure which divides factor loadings by manifestation variable communalities , equalize the influence on rational results of variables with high and low communalities [10:6-46].

Rotation was used to isolate factors with variables. The best results were obtained by using six factors. The results of the SPSS rotation is shown in table 6.

The variables were renamed as follows:

Factor 1	Overseas facilities
Factor 2	Resupply time
Factor 3	Safety stock
Factor 4	Depot replacement time
Factor 5	Conus shipping
Factor 6	Conus facilities

Factorial Design

Introduction. The factorial design ensured that sufficient data were available for the experiment in order to make inferences about each of the LCC model's performances. Two objectives were identified for the data reduction process. First, the factorial design should minimize the number of experiments. Second, because of previous research (2) , only first order interactions will be studied. Given these two objectives, the factorial design determined an experiment that produced approximately

150 factor levels for each LCC model to evaluate. The independent variables that were used for input data to this experiment are the mean time between failure, the number of flying hours and the depot cycle time. The number of facilities and the safety stock level were discarded after identification by the factor analysis, because these variables were not available to all of the models.

TABLE 6

Varimax Rotated Factor Matrix

after Rotation with a Kaiser Normalization

	FACTOR 1	FACTOR 2	FACTOR 3
Q2	.00027	-.00025	-.00039
Q3	.79284	.00332	.00845
Q4	-.79300	.00238	.00709
Q5	.00302	.77836	-.00816
Q6	.00210	-.77853	-.00692
Q7	.00125	-.00116	-.00181
Q8	.00114	-.00106	-.00165
Q9	.00134	-.00125	.99991

(Continued)

	FACTOR 4	FACTOR 5	FACTOR 6
Q2	-.00037	-.00033	1.00000
Q3	.00789	.00720	.00173
Q4	.00662	.00604	.00145
Q5	-00763	-.00696	-.00168
Q6	.00647	-.00590	-.00142
Q7	.99992	-.00154	-.00037
Q8	-.00154	.99993	-.00033
Q9	.00181	-.00165	.00039

Design. A completely randomized factorial (CRF) design with three treatments was developed. A completely randomized factorial design was used because any number of treatment levels could be assigned to the experiment (7:13) and the blocking provides an appropriate format for ANOVA. Although this is not a statistical requirement, the number of levels was selected so that they were equal for all three treatments (7:173). The notation describing the CRF-LLL experiment is:

N = 150 = Maximum number of experiments allowed.
K = 3 = Number of treatments (independent variables).
L = unknown = Number of Levels for each of the treatments, which must be an integer.

The solution for the number of levels was found by:

$$LLL = 150$$

$$L^3 = 150$$

$$L^3 = 150$$

solving by logarithms:

$$3 \text{ LOG } L = \text{LOG } 150$$

$$L = 5.3$$

However, L must be an integer that limits the number of experiments to less than 150. After rounding down to the next integer:

L = 5.3, and after rounding (down) becomes 5.

The calculation of the minimum number of experiments (N) for a CRF-555 is:

N = 5 * 5 * 5

N = 125 experiments

Determination of the Factor Levels. The choice of 5 factor levels for each treatment allows two low points, a medium, and two high points of variation. The values for each of the levels were arbitrarily determined to vary 15 and 30 percent in both positive and negative directions from the mean value of each treatment. The limit of 30 percent was chosen to prevent outliers from the statistical analysis. The actual independent variables for the models were determined by multiplying the nominal value by each factor level and operating the model for that condition. The following chart summarizes the experimental levels for the depot response time (TIME) and operational flying hours (FLYING HOURS). The values for the mean time between failure were obtained by multiplying the variation (VARIATION) by the mean time between failure for each of the different components for the missile.

TABLE 7

Independent Data Values

VARIATION	TIME	FLYING HOURS
-30%	1.07	1.05
-15%	1.30	1.27
0%	1.53	1.50
+15%	1.76	1.72
+30%	1.99	1.95

Data Generation. One hundred twenty five experiments were determined by the different combinations of treatment levels. Each experimental input condition was generated by subsequently iterating the treatment levels. These factor levels were used to change the independent variables of each life cycle cost model, which was then used to compute pipeline spares cost, the dependent variable. This procedure was performed by the four LCC different models (MAVLCC, MAVMOD, MAVMOD-A, HCOM) for the 125 factor levels. The dependent variables from this experiment were accumulated into a data base that was analyzed by the statistical analysis program, SPSS (14).

Input Calculations. Each model's independent variables were modified by the treatments prescribed by the experimental design. The modifications were made when that each model initialized the independent variables. Modifications were made to the mean time between failure, the number of flying hours, and the depot response time. The mean time between failure is different for each of the Guidance Control System (GCS), Hydraulic Actuator System (HAS), and the Aft Section. Also, there are differences in failure rates for the AFT and GCS for the tactical (AGM) and the training (TGM) missile. These values are kept in the "XM(I,J) matrix for the MAVLCC, MAVMOD, and MAVMOD-A models. However, HCOM is slightly different because it changes the

failure rates of the GCS, HAS, and AFT section by a multiplier that is kept in the "g(1)" array.

Treatments for Failure Rates

MAVLCC, MAVMOD, and MAVMOD-A Treatments. The changes were made in subroutine MAV4 after the mean time between failure independent variables were initialized by the model. A FORTRAN "do loop" was installed in MAV4 to modify the variables by the experimental treatment (XMVAL). This subprogram multiplies each of the 27 different failure rates by the treatment, and then re-assigns that value to the same variable name in the XM matrix.

```
      DO 87 IX = 1,3
      DO 87 IY = 1,9
      XM(IX,IY) = XM(IX,IY) * XMVAL
   87 CONTINUE
```

where:

```
IX = Missile status
     1 = Operational
     2 = Storage
     3 = Alert

IY = Missile component
     1 = AGM - Guidance Control System
     2 = AGM - Aft Section
     3 = AGM - Hydraulic Actuation System
     4 = TGM - Guidance Control System
     5 = TGM - Recorder
     6 = TGM - Signal Processor
     7 = TGM - Aft Section
     8 = Launcher - Electrical System
     9 = Launcher - Mechanical System

XMVAL = Experimental Treatment
```

HCOM Treatments. The treatment to the mean time between failure was made in the EQATN subroutine, which calculates the system life cycle costs. Two modifications in HCOM are necessary: first, changes to the operating failure rate, and second, to the storage failure rate. These two variables, mean time between failure and failure rate are inversely related, which require that the treatments also be inversely adjusted. The treatments were applied to the FORTRAN program as follows:

1.) Treatment to the mean time between failure-G(1).

G(1) = G(1) * XMVAL

2.) Treatment to the failure rate-FPCH

FPCH = FPCH / XMVAL

where:

G(1) = Multiplier for the mean time between failure

FPCH = failure rate (Hours)

XMVAL = Treatment for the mean time between failure

Treatments for FLYING HOURS

MAVLCC, MAVMOD, and MAVMOD-A Treatments. The flying hour treatments were made in subroutine MAV17 to both the tactical flying hours (SHR) and the training flying hours (TGMHR) independent variables as they were initialized by the model. This required two FORTRAN statements:

1.) Treatment for the tactical missile:

SHR = SHR * FHVAL

2.) Treatment to the training missile:

TGMHR = TGMHR * FHVAL

where:

SHR = Number of tactical flying hours

TGMHR = Number of training flying hours

FHVAL = Flying Hours Treatment

HCOM Treatments. System flying hours were not an input variable to HCOM, rather the variable hours usage (HRSUSE) is used to calculate life cycle costs. These variable were interchangeable because the method that they used to calculate system failures is comparable. The treatment for hours usage is made at the time system data is initialized in subroutine SYSD. The FORTRAN statement is:

HRSUSE = HRSUSE * FHVAL

where:

HRSUSE = Number of operational usage system hours

FHVAL = Flying hours treatment

Treatments for Depot Response Time

MAVLCC, MAVMOD, and MAVMOD-A Treatments. The treatments to the depot response times were made in subroutine MAV4 after the independent variables were initialized by the model. A FORTRAN "do loop" was installed to modify the depot response variables, defined by the DRCT (9) array, with the experimental treatment (DTVAL). This subprogram multiplies the nine depot response times, which are nominally the same

at 1.53 months, by the treatment, and then re-assigns that value to the same variable name in the DRCT array. For example,

```
      DO 88 IY = 1,9
      DCRT(IY) = DCRT(IY) * DTVAL
   88 CONTINUE
```

where:

IY = Missile component
- 1 = AGM - Guidance Control System
- 2 = AGM - Aft Section
- 3 = AGM - Hydraulic Actuation System
- 4 = TGM - Guidance Control System
- 5 = TGM - Recorder
- 6 = TGM - Signal Processor
- 7 = TGM - Aft Section
- 8 = Launcher - Electrical System
- 9 = Launcher - Mechanical System

DCRT = Depot Response time (nominally 1.5 months)

DTVAL = Depot Response Time Treatment

<u>HCOM Treatments</u>. The depot cycle time is not used by HCOM. Rather, the array PIPE(4,1), the one-way pipeline time (months) is used to calculate the required number of pipeline spare parts. This array contains estimates for high and low values for both the continental and overseas bases. The treatment is applied in the subroutine ITEMD when the array is read from the data file. A FORTRAN subprogram treats the array PIPE and then places the treated value in the same location in PIPE. For example,

```
      DO 500 IK = 1,4
      PIPE(IK,1) = PIPE(IK,1) * DTVAL
  500 CONTINUE
```

where:

IK = System Status
1 - Conus High Rate (nominally .83)
2 - Overseas High Rate (nominally .97)
3 - Conus Low Rate (nominally .7)
4 - Overseas Low Rate (nominally .83)

DTVAL = Depot Cycle Response Treatment

Experimentation Procedure

Each of the life cycle cost models were modified to facilitate the 125 computations of pipeline cost. Once the standard Maverick values had been established, all of the computer runs were completed with the nominal values, plus the application of treatments to the mean time between failure, the number of flying hours, and the depot response time. The modifications to the models included changes to:

1. Suppress queries for date, titles,etc.
2. Suppress printing of normal model output reports.
3. Provide experimental treatments.
4. Print pipeline costs,the dependent variable, to an output file.

The flow of events for model computations are identical for the Maverick Models (MAVLCC, MAVMOD, and MAVMOD-A). The process was to read a data record which specified the treatment, initialize nominal conditions, perform the computations, write the output to a disk file, close all files and programs, then reinitiate the process until all the treatments were applied. It was necessary to open and close all of the program files for each program run, because several variables within the program are not correctly initialized during computations.

The flow of events for operating the Hughes Cost of Ownership Model was similar to the Maverick Model's, but similar because it was not necessary to close the program to change the application of different treatments.

Summary

Chapter III described the experimental process that developed the pipeline cost data base (shown in Appendix A). This data base was used for analysis of variance (ANOVA) and regression analysis.

The selection of independent variables (factors) was determined by performing a factor analysis experiment. The MOD-METRIC spares subroutine was used to calculate pipeline spares based on independent variables (number of conus bases, number of overseas bases, number of overseas sites, depot replacement time, conus shipping time, depot safety stock factor). The spares model calculated the required number of line replaceable units (LRUs) and shop replaceable units (SRUs). The mean time between failure (not an input into the Mod-Metric subroutine) was included because of the significance in life cycle cost models. Three independent variables were included for independent variables mean time between failure, number of flying hours, and depot cycle time. The number of treatments was selected to provide enough observations for a statistical analysis, and also to maintain data processing economy. The life cycle cost

models, MAVLCC, MAVMOD, MAVMOD-A, and HCOM, were modified so that computations could be made with minimal manual manipulation. The LCC models were modified by specifying treatments for the independent variables at the time the variables were intialized. Further modifications were made in order to suppress data query and disk output printing. Each model was then run for the 125 different treatments to calculate the dollar cost of the required pipeline spare parts.

IV. Analysis of Results

Introduction

This chapter analyzes the results of the simulation study. A brief review is provided of the experimental procedure that developed the data base. The data base is an amalgamation of the independent and dependent variables for each of the models. Four models were used for the study: The Hughes Cost of Ownership Model (HCOM), the MOD-METRIC Maverick (MAVMOD), the Maverick Life Cycle Cost Model (MAVLCC), and the Modified MOD-METRIC Maverick (MAVMOD-A). The independent variables were depot cycle time, number of flying hours, and the mean time between failure. The dependent variable is pipeline cost. Pipeline cost, the value of spare parts that is required to fill the logistics pipeline, was computed by each life cycle cost model for 125 factor levels. The first step in the analysis confirmed that statistical distributions of the data complied with the assumptions for an Analysis of Variance (ANOVA) model. Examination of the data base compliance to ANOVA assumptions was performed by a graphical residual analysis. The graphical analysis determined that a Base 10 logarithm (LOG_{10}) was required for transforming the pipeline costs. Although the independent variables were identified by a factor analysis, the statistical significance of each of the independent variables (depot cycle time, number of flying

hours, and mean time between failure) was examined with all four life cycle cost models (HCOM, MAVMOD, MAVLCC, and MAVMOD-A). Finally, there is a discussion of the results of Tukey's Multiple Comparison Tests. Tukey's procedure was determined differences in the mean value of pipeline costs calculated among the factor levels for each life cycle cost model. The procedural tasks required to generate and analyze the data were:

1. Use the four models, HCOM, MAVMOD, MAVLCC, and MAVMOD-A to calculate pipeline costs.
2. Confirm that the data base conforms to the assumptions of an ANOVA.
3. Determine the statistical significance of the depot cycle time (DEPOT), number of flying hours (FLYING), and mean time between failure (MTBF)
4. Determine the effect of the factor levels and their interactions on pipeline costs for HCOM, MAVMOD, MAVLCC, MAVMOD-A.
5. Perform a multiple comparison of the models to determine difference in the means of the life cycle cost models and the factor levels.

Tests of the Data

The data base computed by the four life cycle cost models was analyzed for conformance to statistical assumptions of ANOVA. ANOVA assumes that the observations

of pipeline costs are independent and identically distributed with a mean of zero and standard deviation of one. Conformance to ANOVA assumptions are achieved by verification of two criteria:

1. The observations of pipeline costs must be normally distributed for each life cycle cost model.
2. The variance of the observations among the factor levels must be stable.

The verification of ANOVA assumptions was performed by a graphical analysis of the residuals. Residuals are the differences between predicted pipeline costs (determined by the regression model) and actual pipeline costs (determined by the life cycle cost model). For each life cycle cost model, two residual graphs were produced, a histogram and a scatterplot. A histogram plot was made of the standardized residuals to examine for departures from normality, and the scatterplot was used to examine for the stability of the variance among the factor levels.

The ANOVA assumptions analysis is divided into two sections. First, an analysis is provided of the pipeline costs. The analysis examines the mean, standard deviation, variance, kurtosis, and skewness. Second, a graphical analysis is provided to highlight departures from ANOVA model assumptions and provide insight into possible base transformations.

Analysis of the Data Base. The means, standard deviations, kurtosis, and skewness were computed for each of the LCC model's calculation for pipeline costs (dependent variables). These values are shown in Table 8.

TABLE 8

Model Output Summary Statistics [1]

Model	HCOM	MAVMOD	MAVLCC	MAVMOD-A
Mean	$58.6	$118.3	$39.1	$51.1
Standard Deviation	$32.3	$32.5	$12.7	$11.4
Variance	$1,043.3	$1,056.2	$161.3	$130.0
Maximum Value	$149.3	$215.3	$80.0	$85.3
Minimum Value	$18.2	$62.0	$18.9	$31.3
Kurtosis	.707	.077	.215	-.066
Skewness	1.105	.660	.731	.546

[1] Dollars are shown in Millions

Mean pipeline costs range from $39.1 million for the Maverick Life Cycle Cost Model (MAV) to $118.3 million for the MOD-METRIC Maverick Life Cycle Cost Model (MAVMOD). Although the MAVLCC and MAVMOD models appear to compute different pipeline costs for spares, there are not any

practically significant differences in values between the Hughes Cost of Ownership Model (HCOM), the Maverick Life Cycle Cost Model (MAV), and a modified version of the MOD-METRICS Maverick (MAVMOD-A).

The variances shown in TABLE 6 show that pipeline costs variance range from $130.0 for MAVMOD-A to $1043.3 for HCOM. The variance for HCOM and MAVMOD are equal, but they both differ from MAVLCC and MAVMOD-A. The second assumption of ANOVA requires that the variance among the factor levels computed for each model are equal. Equality of the variances may be determined by direct observation. As Devore (4:288) claims:

> Our approach is simply to "eyeball" [visually compare] the two sample variances; if they are roughly the same order of magnitude, then one can be comfortable in using [a pairwise comparison test].

The kurtosis is the lowest at -.066 for MAVMOD-A and ranged to .707 for HCOM. The kurtosis is .077 for MAVMOD and .215 for MAVLCC. Non-normality is indicated by kurtosis in the pipeline costs observations. A normal distribution has a kurtosis of zero; positive values indicate a larger peaked distribution and negative values indicate less peaked distributions.

The skewness is the lowest at .546 for MAVMOD-A and ranged to 1.105 for HCOM. The skewness is .66 for MAVMOD and .731 for MAVLCC. Although the skewness is less important than kurtosis when considering normality (13:513), it can be used to determine the deviation that the

distribution has from symmetry; a skewness of zero indicate a bell shaped curve, positive values describe curves that are skewed to the right, and negative values represent curves that are skewed to the left.

A Graphical Analysis. A plot of the residuals was performed by a regression model for each of the life cycle cost models. The residuals were inspected for normality and a constant variance. Residuals are those values that are the difference between the predicted costs and the actual costs produced by each life cycle cost model. The SPSS histogram of residuals was used for the normality check and the presence of outliers in the data. The SPSS scatterplot of residuals was used to check the homogeneity of the variance among the factor levels.

Histogram Analysis. Figures 2-5 show the histograms of the residuals for the four different models (HCOM, MAVMOD, MAV, and MAVMOD-A). The interpretation of the SPSS output supplies information by the number of counts, the expected number of counts, the standard normal random variable, and a graphic representation of the number of counts contrasted with expected counts. The data was separated into 21 intervals (determined by SPSS). The actual number of residuals was counted in each interval, and the expected number of residuals was determined by the program corresponding to the expected number of points in a standard normal curve. The graphic representation of the

actual and expected data is plotted next to the corresponding values. The graphic "*" represents one residual in the corresponding interval. The solid line represents the standard normal curve.

All of the models have histogram residuals that are positively skewed and each distribution has outliers. The normal distributions are robust to skewness, but not for outliers (13:513). The presence of these extreme values can significantly affect the least-squares fitting of the ANOVA models. The outliers for each of the models correspond with large values of the mean time between failure, which decreases the requirement for pipeline spares.

<u>Variance Analysis</u>. The scatterplots produced by SPSS were used to determine information concerning the variances of the residuals for the different LCC models. The scatterplots depict the standardized residuals with the vertical scale of predicted residuals and the horizontal scale of residuals. With a completely normal distribution, there would be a horizontal band of points centered at zero on the vertical axis, and there would not be any trends of distinguishable patterns in the data. Each of the models showed instability of error variances, which is shown by a trapezoidal graphic. There are distinguishable patterns that shown in figures 6-9.

N	EXP N		
0	.10	OUT	
4	.19	3.00	****
0	.49	2.66	
0	1.12	2.33	
6	2.28	2.00	******
4	4.18	1.66	****
5	6.86	1.33	*****
1	10.08	1.00	*
14	13.28	0.66	**************
0	15.66	0.33	
20	16.55	0.00	********************
20	15.66	-0.33	********************
26	13.28	-0.66	**************************
25	10.08	-1.00	*************************
0	6.86	-1.33	
0	4.18	-1.66	
0	2.28	-2.00	
0	1.12	-2.33	
0	.49	-2.66	
0	.19	-3.00	
0	.10	OUT	

FIGURE 2. Histogram of Standardized Residuals for The Hughes Cost of Ownership Model

LEGEND

N = NUMBER OF COUNTS IN INTERVAL

EXP N = EXPECTED NUMBER OF COUNTS IN A STANDARDIZED NORMAL INTERVAL

* = GRAPHIC OF ONE COUNT

```
 N EXP N

 1    .10   OUT   *
 1    .19  3.00   *
 2    .49  2.66   **
 2   1.12  2.33   **
 2   2.28  2.00   **
 3   4.18  1.66   ***
 4   6.86  1.33   ****
 8  10.08  1.00   ********
 6  13.28  0.66   ******
13  15.66  0.33   *************
14  16.55  0.00   **************
21  15.66 -0.33   *********************
29  13.28 -0.66   *****************************
14  10.08 -1.00   **************
 4   6.86 -1.33   ****
 1   4.18 -1.66   *
 0   2.28 -2.00
 0   1.12 -2.33
 0    .49 -2.66
 0    .19 -3.00
 0    .10   OUT
```

FIGURE 3. Histogram of Standardized Residuals for the MOD-METRIC Maverick Life Cycle Cost Model

LEGEND

N	=	NUMBER OF COUNTS IN INTERVAL
EXP N	=	EXPECTED NUMBER OF COUNTS IN A STANDARDIZED NORMAL INTERVAL
*	=	GRAPHIC OF ONE COUNT

```
 N  EXP N

 1    .10   OUT    *
 1    .19  3.00    *
 0    .49  2.66
 1   1.12  2.33    %
 4   2.28  2.00    *%**
 2   4.18  1.66    **
 6   6.86  1.33    ******
 8  10.08  1.00    ********
 8  13.28  0.66    ********
14  15.66  0.33    **************
21  16.55  0.00    ****************%****
18  15.66 -0.33    ***************%**
14  13.28 -0.66    ************%*
17  10.08 -1.00    *********%*******
 8   6.86 -1.33    ******%*
 2   4.18 -1.66    **
 0   2.28 -2.00
 0   1.12 -2.33
 0    .49 -2.66
 0    .19 -3.00
 0    .10   OUT
```

FIGURE 4. Histogram of Standardized Residuals for the Maverick Life Cycle Cost Model

LEGEND

N	=	NUMBER OF COUNTS IN INTERVAL
EXP N	=	EXPECTED NUMBER OF COUNTS IN A STANDARDIZED NORMAL INTERVAL
*	=	GRAPHIC OF ONE COUNT

```
 N EXP N

 1    .10    OUT   *
 2    .19   3.00   **
 0    .49   2.66
 3   1.12   2.33   ***
 0   2.28   2.00
 5   4.18   1.66   *****
 6   6.86   1.33   ******
 6  10.08   1.00   ******
 9  13.28   0.66   *********
11  15.66   0.33   ***********
21  16.55   0.00   *********************
19  15.66  -0.33   *******************
16  13.28  -0.66   ****************
18  10.08  -1.00   ******************
 7   6.86  -1.33   *******
 1   4.18  -1.66   *
 0   2.28  -2.00
 0   1.12  -2.33
 0    .49  -2.66
 0    .19  -3.00
 0    .10    OUT
```

FIGURE 5. Histogram of Standardized Residuals for the Modified MOD-METRIC Maverick Model

LEGEND

N	=	NUMBER OF COUNTS IN INTERVAL
EXP N	=	EXPECTED NUMBER OF COUNTS IN A STANDARDIZED NORMAL INTERVAL
*	=	GRAPHIC OF ONE COUNT

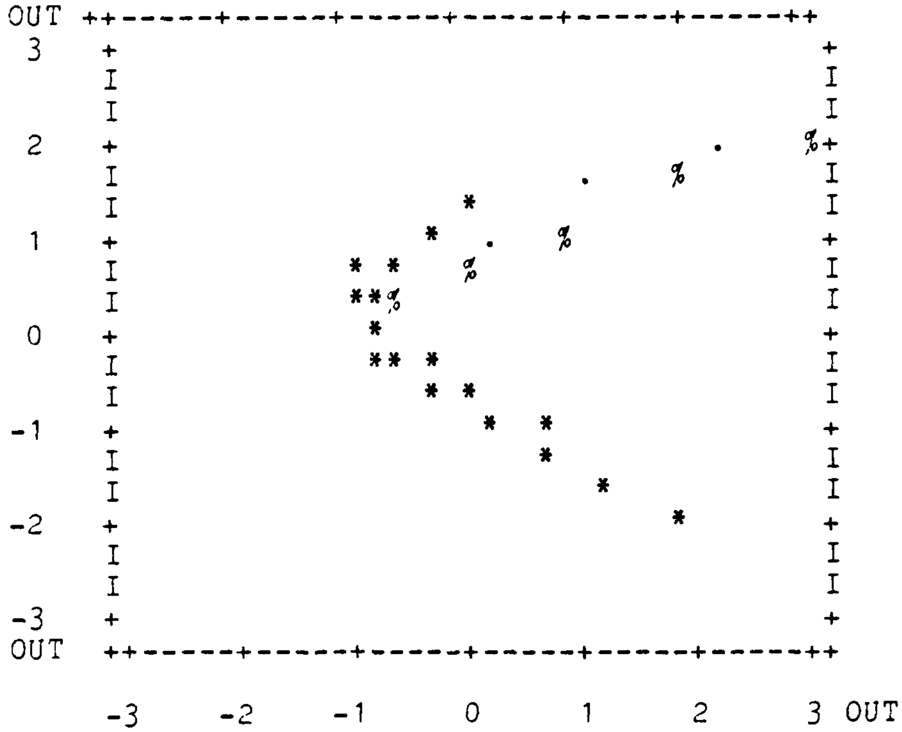


FIGURE 6. Scatterplot of Standardized Residuals for the Hughes Cost of Ownership Model

LEGEND

ACROSS = STANDARDIZED RESIDUALS
DOWN = STANDARDIZED PREDICTED RESIDUALS
. = GRAPHIC OF TWO COUNTS
% = GRAPHIC OF FOUR COUNTS
* = GRAPHIC OF TEN COUNTS

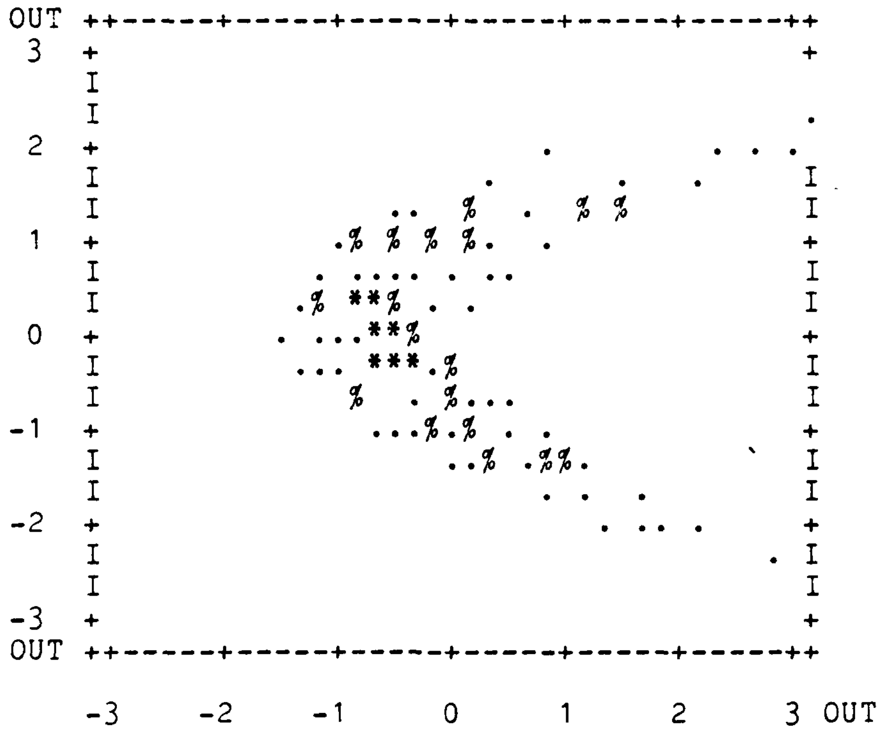


FIGURE 7. Scatterplot of Standardized Residuals for the MOD-METRIC Maverick Life Cycle Cost Model

LEGEND

ACROSS = STANDARDIZED RESIDUALS
DOWN = STANDARDIZED PREDICTED RESIDUALS
. = GRAPHIC OF ONE COUNT
% = GRAPHIC OF TWO COUNTS
* = GRAPHIC OF SEVEN COUNTS

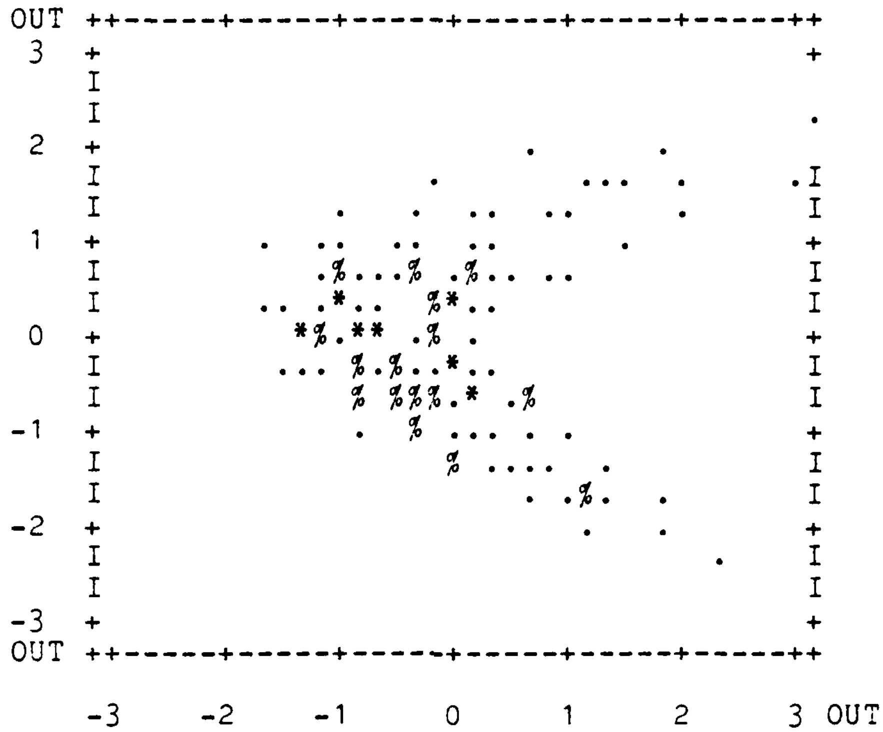


FIGURE 8. Scatterplot of Standardized Residuals for the Maverick Life Cycle Cost Model

<u>LEGEND</u>

ACROSS	=	STANDARDIZED RESIDUALS
DOWN	=	STANDARDIZED PREDICTED RESIDUALS
.	=	GRAPHIC OF ONE COUNT
%	=	GRAPHIC OF TWO COUNTS
*	=	GRAPHIC OF FOUR COUNTS

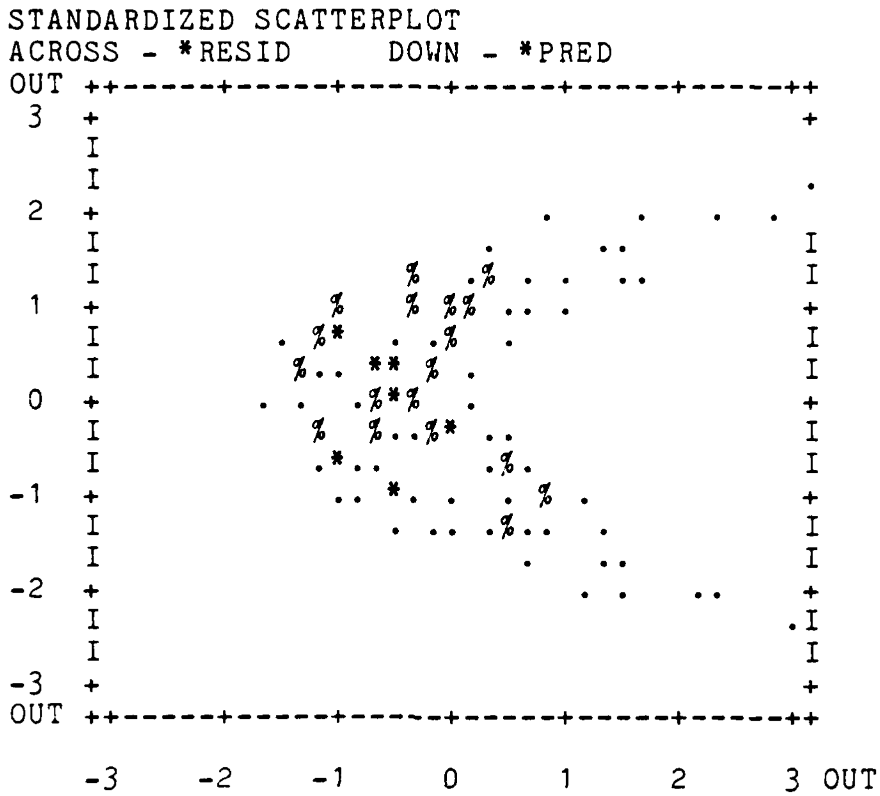


FIGURE 9. Scatterplot of Standardized Residuals for the Modified MOD-METRIC Maverick Model

LEGEND

ACROSS	=	STANDARDIZED RESIDUALS
DOWN	=	STANDARDIZED PREDICTED RESIDUALS
.	=	GRAPHIC OF ONE COUNT
%	=	GRAPHIC OF TWO COUNTS
*	=	GRAPHIC OF SIX COUNTS

Data Transformations

Introduction. The residual analysis indicated that the data base did not conform to the assumptions required for ANOVA models. Outliers in the histograms caused rejection of the normality assumption, and trapezoidal scatterplots indicated instability of variances among the factor levels. These wo deviations indicate that pipeline costs should be transformed (restructured). A base 10 logarithm (LOG_{10}) transformation was used. A LOG_{10} can be used when the variance (dependent variable) increases markedly as the dependent variable increases. A second application for a LOG_{10} is to normalize the distribution when the residuals are positively skewed (8:242).

The transformation was performed by calculating the LOG_{10} of each pipeline costs. After the pipeline costs had been transformed, they were re-examined for conformance to ANOVA assumptions and checked for normality and stability of the residual variances among factor levels. This section analyzes the results of the LOG_{10} transformation. An analysis of the mean, standard deviation, variance, kurtosis, and skewness are supplied. Next, the histograms of standardized residuals for HCOM, MAVMOD, MAVLCC, and MAVMOD-A are shown, depicting the results from the transformation. Finally the four scatterplots of standardized residuals with a LOG_{10} transformation are provided for each of the life cycle cost models.

Results. The analysis for normality and stability of factor level variances was then repeated after performing the LOG_{10} transformation. The transformed summary statistics are shown in Table 9. The transformation of the data removed residual outliers from the data base. Also, the instability of the variance was corrected by the transformation. The scatterplots 14-17 do not show any discernible pattern, which indicates stable variances of the residuals. ANOVA models using this transformed data base could then be apt based on statistical distributions of the residual terms.

Table 9

Model Output Summary Statistics

after the LOG_{10} Transformation

	HCOM	MAVMOD	MAVLCC	MAVMOD-A
Mean	7.71	8.057	7.57	7.703
Standard Deviation	.232	.118	.14	.095
Variance	.054	.014	.019	.009
Maximum Value	8.174	8.333	7.903	7.931
Minimum Value	7.259	7.792	7.276	7.496
Kurtosis	-.677	-.492	-.522	-.511
Skewness	.081	.05	.015	.055

```
 N  EXP N
 0    .10    OUT
 0    .19   3.00
 0    .49   2.66
 0   1.12   2.33
 4   2.28   2.00   ****
13   4.18   1.66   *************
10   6.86   1.33   **********
 0  10.08   1.00
 8  13.28   0.66   ********
16  15.66   0.33   ****************
18  16.55   0.00   ******************
15  15.66  -0.33   ***************
11  13.28  -0.66   ***********
15  10.08  -1.00   ***************
 5   6.86  -1.33   *****
10   4.18  -1.66   **********
 0   2.28  -2.00
 0   1.12  -2.33
 0    .49  -2.66
 0    .19  -3.00
 0    .10    OUT
```

FIGURE 10. Histogram of Standardized Residuals for The Hughes Cost of Ownership Model with a LOG_{10} Transformation

LEGEND

N	=	NUMBER OF COUNTS IN INTERVAL
EXP N	=	EXPECTED NUMBER OF COUNTS IN A STANDARDIZED NORMAL INTERVAL
*	=	GRAPHIC OF ONE COUNT

```
 N EXP N

 0    .10    OUT
 0    .19   3.00
 0    .49   2.66
 0   1.12   2.33
 3   2.28   2.00   ***
 8   4.18   1.66   ********
 8   6.86   1.33   ********
 8  10.08   1.00   ********
 9  13.28   0.66   *********
11  15.66   0.33   ***********
23  16.55   0.00   ***********************
20  15.66  -0.33   ********************
 6  13.28  -0.66   ******
12  10.08  -1.00   ************
 9   6.86  -1.33   *********
 5   4.18  -1.66   *****
 2   2.28  -2.00   **
 1   1.12  -2.33   *
 0    .49  -2.66
 0    .19  -3.00
 0    .10    OUT
```

FIGURE 11. Histogram of Standardized Residuals for The MOD-METRIC Maverick Life Cycle Cost Model with a LOG_{10} Transformation

LEGEND

N	=	NUMBER OF COUNTS IN INTERVAL
EXP N	=	EXPECTED NUMBER OF COUNTS IN A STANDARDIZED NORMAL INTERVAL
*	=	GRAPHIC OF ONE COUNT

```
 N EXP N
 0   .10    OUT
 0   .19   3.00
 0   .49   2.66
 0  1.12   2.33
 2  2.28   2.00  *%
 9  4.18   1.66  ***%*****
 2  6.86   1.33  **
14 10.08   1.00  *********%****
17 13.28   0.66  *************%***
10 15.66   0.33  **********
17 16.55   0.00  ****************%
18 15.66  -0.33  ***************%**
 6 13.28  -0.66  ******
11 10.08  -1.00  *********%*
13  6.86  -1.33  ******%******
 1  4.18  -1.66  *
 5  2.28  -2.00  *%***
 0  1.12  -2.33
 0   .49  -2.66
 0   .19  -3.00
 0   .10    OUT
```

FIGURE 12. Histogram of Standardized Residuals for The Maverick Life Cycle Cost Model with a LOG_{10} Transformation

<u>LEGEND</u>

N	=	NUMBER OF COUNTS IN INTERVAL
EXP N	=	EXPECTED NUMBER OF COUNTS IN A STANDARDIZED NORMAL INTERVAL
*	=	GRAPHIC OF ONE COUNT

```
 N  EXP N
 0    .10    OUT
 0    .19   3.00
 0    .49   2.66
 0   1.12   2.33
 1   2.28   2.00   *
 7   4.18   1.66   *******
10   6.86   1.33   **********
 9  10.08   1.00   *********
18  13.28   0.66   ******************
14  15.66   0.33   **************
11  16.55   0.00   ***********
13  15.66  -0.33   *************
10  13.28  -0.66   **********
15  10.08  -1.00   ***************
10   6.86  -1.33   **********
 6   4.18  -1.66   ******
 1   2.28  -2.00   *
 0   1.12  -2.33
 0    .49  -2.66
 0    .19  -3.00
 0    .10    OUT
```

FIGURE 13. Histogram of Standardized Residuals for The Modified MOD-METRIC Maverick Model with a LOG_{10} Transformation

LEGEND

N	=	NUMBER OF COUNTS IN INTERVAL
EXP N	=	EXPECTED NUMBER OF COUNTS IN A STANDARDIZED NORMAL INTERVAL
*	=	GRAPHIC OF ONE COUNT

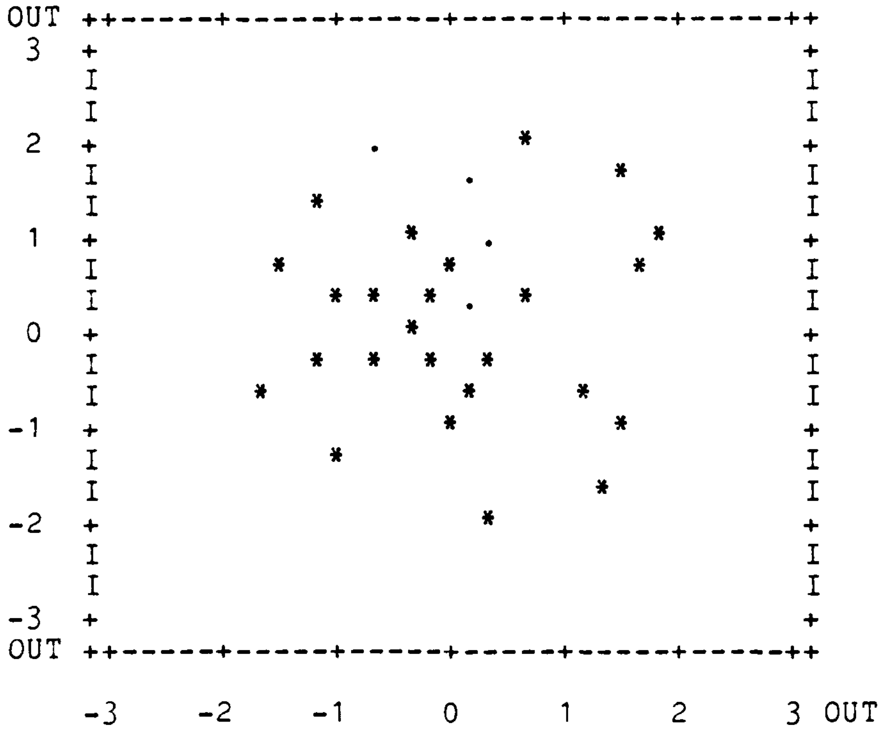


FIGURE 14. Scatterplot of Standardized Residuals for The Hughes Cost of Ownership Model with a LOG_{10} Transformation

LEGEND

ACROSS	=	STANDARDIZED RESIDUALS
DOWN	=	STANDARDIZED PREDICTED RESIDUALS
.	=	GRAPHIC OF ONE COUNT
%	=	GRAPHIC OF TWO COUNTS
*	=	GRAPHIC OF SIX COUNTS

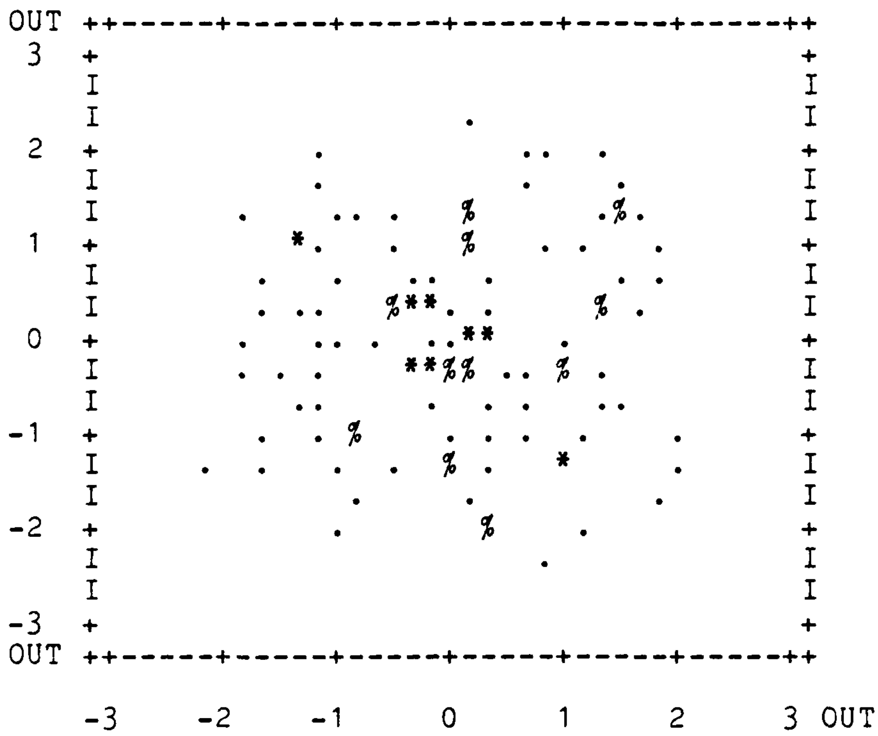


FIGURE 15. Scatterplot of Standardized Residuals for The MOD-METRIC Maverick Life Cycle Cost Model with a LOG_{10} Transformation

<u>LEGEND</u>

ACROSS = STANDARDIZED RESIDUALS
DOWN = STANDARDIZED PREDICTED RESIDUALS
. = GRAPHIC OF ONE COUNT
% = GRAPHIC OF TWO COUNTS
* = GRAPHIC OF SEVEN COUNTS

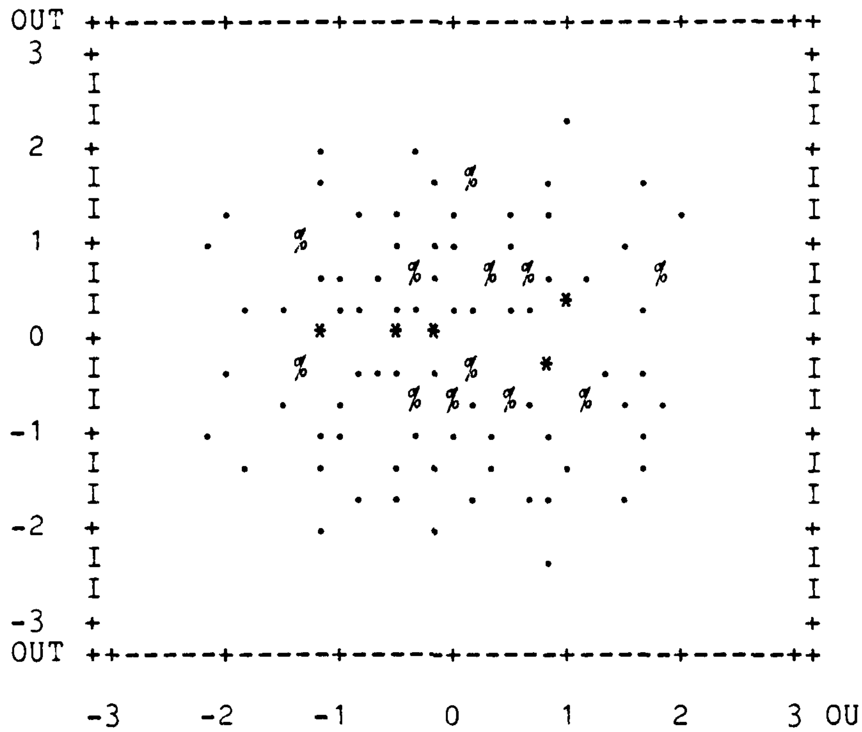


FIGURE 16. Scatterplot of Standardized Residuals for The Maverick Life Cycle Cost Model with a LOG_{10} Transformation

LEGEND

ACROSS	=	STANDARDIZED RESIDUALS
DOWN	=	STANDARDIZED PREDICTED RESIDUALS
.	=	GRAPHIC OF ONE COUNT
%	=	GRAPHIC OF TWO COUNTS
*	=	GRAPHIC OF SIX COUNTS

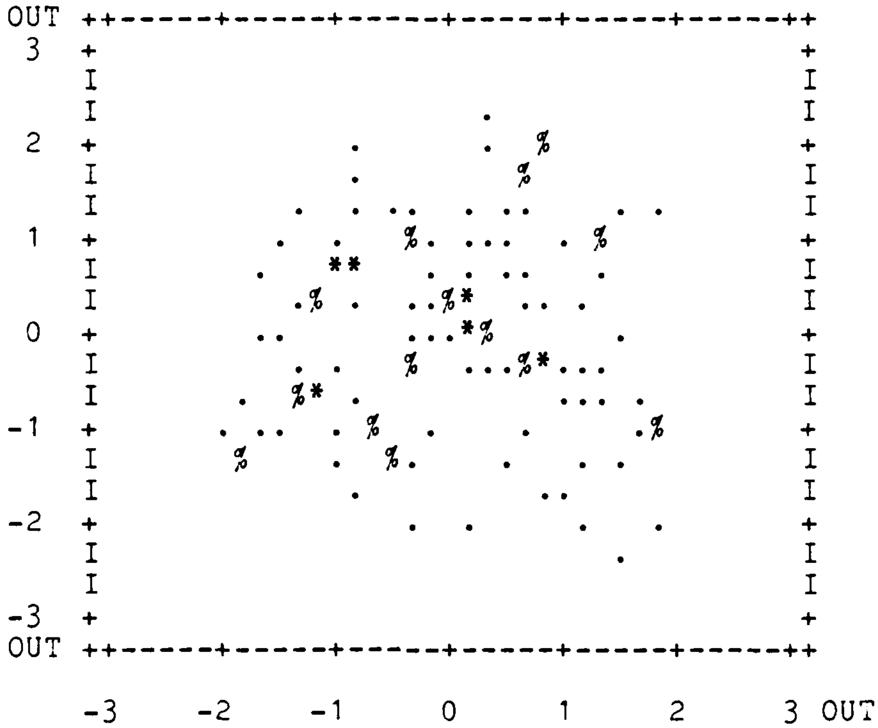


FIGURE 17. Scatterplot of Standardized Residuals for The Modified MOD-METRIC Maverick Model with a LOG_{10} Transformation

LEGEND

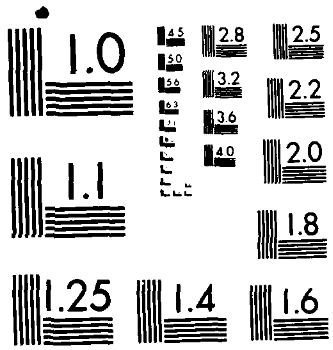
ACROSS = STANDARDIZED RESIDUALS
DOWN = STANDARDIZED PREDICTED RESIDUALS
. = GRAPHIC OF ONE COUNT
% = GRAPHIC OF TWO COUNTS
* = GRAPHIC OF FIVE COUNTS

The Significance Test

Introduction. Analysis of the LOG_{10} transformation indicated that the transformed pipeline costs conform to the assumptions of normal distributions and stable variances for ANOVA models. This section explains the relative effect that each of the independent variables, depot cycle time (DEPOT), the number of flying hours (FLYING), and mean time between failure (MTBF) have upon the dependent variable, pipeline costs. The "relative effect" that the independent variables have upon dependent variables are measured by the "F" statistic. The F statistic indicates the amount of explained variation in pipeline costs indicated by the independent variable. A large F value indicates that a large variation in the dependent variable is explained by the independent variable, and small F value explains less of the pipeline costs. This chapter is structured to provide an analysis of one life cycle cost model at a time (HCOM, MAVMOD, MAVLCC, MAVMOD-A). Each of the independent variables (DEPOT, FLYING, and MTBF) were examined for each model. Finally, a two-way factor ANOVA examined the effect of interactions between the independent variables. In these ANOVA models, interactions are the combined effects of two of the independent variables on pipeline costs.

The Hypothesis Test. The input data was tested to confirm that each independent variable was significant for the ANOVA model. The hypothesis test examined each

AD-A162 283 EVALUATION OF SPARING MODELS FOR A MISSILE SYSTEM(U) 2/2
AIR FORCE INST OF TECH WRIGHT-PATTERSON AFB OH SCHOOL
OF SYSTEMS AND LOGISTICS L A GREENE SEP 85
UNCLASSIFIED AFIT/GSM/LSY/85S-15 F/G 14/1 NL



MICROCOPY RESOLUTION TEST CHART
NATIONAL BUREAU OF STANDARDS-1963-A

independent variable with the dependent variable. The independent variables are depot cycle time, number of flying hours, and The mean time between failure; the dependent variable is the cost of pipeline spares computed by HCOM, MAVMOD, MAVLCC, and MAVMOD-A LCC models. The data was divided into five groups, which correspond to the treatment levels for each of the factors. The F tests were performed at a significance level of $\alpha = .05$, the probability of a type I error (risk of rejecting the null hypothesis when the null hypothesis is true). The F value, the mean square, is the ratio of the sum of squares of explained variation divided by the total variation. The F statistic describes the ratio of explained variation for each of the factors (independent variables). The F statistic positively correlates with a "goodness of fit" between the independent variable and the dependent variable. The null hypothesis (H_o)for the significance tests is that the variables are <u>not</u> statistically significant in affecting the value of the dependent variable.

H_o: the Explained Variation is <u>not</u> significant

The alternate hypothesis (H_a) is that the independent variables are statistically significant in affecting the value of the dependent variables.

H_a: The Explained Variation is significant.

Analysis of the HCOM Model. The HCOM model analysis is presented in ANOVA Tables 10-12. Table 10 shows HCOM by the depot cycle time, Table 11 is HCOM by the flying hours, and Table 12 is HCOM by the mean time between failure. The factors depot cycle time and mean time between failure were significant predictors of the HCOM model; the number of flying hours was not a predictor of HCOM.

Relatively, most of the variation in HCOM is accounted for by the mean time between failure (80.1%) and the depot cycle time explains the next highest amount of the variation (19.9%). The number of flying hours was not statistically significant in predicting pipeline cost in HCOM. The F statistic for the flying hours is only .002 and the F for rejection is .999.

TABLE 10

Analysis of Varaince Data

HCOM by Depot Cycle Time

SOURCE OF VARIATION	SUM OF SQUARES	DF	MEAN SQUARE	F	SIGNIF OF F
DEPOT CYCLE TIME	2.214	4	.553	14.941	.001
RESIDUAL	4.445	120	.037		
TOTAL	6.659	124	.054		

TABLE 11

Analysis of Variance Data

HCOM by Flying Hours

SOURCE OF VARIATION	SUM OF SQUARES	DF	MEAN SQUARE	F	SIGNIF OF F
FLYING	.000	4	.000	.002	.999
RESIDUAL	6.658	120	.055		
TOTAL	6.659	124	.054		

TABLE 12

Analysis of Variance Data

HCOM by MTBF

SOURCE OF VARIATION	SUM OF SQUARES	DF	MEAN SQUARE	F	SIGNIF OF F
MTBF	4.442	4	1.111	60.129	.001
RESIDUAL	2.216	120	.018		
TOTAL	6.659	124	.054		

Analysis of the MAVMOD Model. The MAVMOD Model's analysis is shown in ANOVA tables 13-15. Table 13 shows MAVMOD by the depot cycle time, Table 14 is MAVMOD by the flying hours, and Table 15 is MAVMOD by the mean time between failure. All of the independent variables were statistically significant in the MAVMOD ANOVA model.

The variation in MAVMOD's pipeline cost is explained mostly by the mean time between failure (46.9 %) and the depot cycle time (46.4 %). The least explanation is provided by the number of flying hours (6.7 %).

TABLE 13

Analysis of Variance Data

MAVMOD by Depot Cycle Time

SOURCE OF VARIATION	SUM OF SQUARES	DF	MEAN SQUARE	F	SIGNIF OF F
DEPOT CYCLE TIME	.765	4	.191	24.217	.001
RESIDUAL	.948	120	.008		
TOTAL	1.713	124	.014		

TABLE 14

Analysis of Variance Data

MAVMOD by Flying Hours

SOURCE OF VARIATION	SUM OF SQUARES	DF	MEAN SQUARE	F	SIGNIF OF F
FLYING	.177	4	.044	3.466	.010
RESIDUAL	1.536	120	.013		
TOTAL	1.713	124	.014		

TABLE 15

ANALYSIS OF VARIANCE DATA

MAVMOD BY MTBF

SOURCE OF VARIATION	SUM OF SQUARES	DF	MEAN SQUARE	F	SIGNIF OF F
MTBF	.769	4	.192	24.463	.001
RESIDUAL	.944	120	.008		
TOTAL	1.713	124	.014		

<u>Analysis of the MAVLCC Model</u>. The Maverick Life Cycle Cost Model's analysis is shown in ANOVA tables 16-18, Table 16 shows MAVLCC by the depot cycle time, Table 17 is MAVLCC by the flying hours, and Table 18 is MAVLCC by the mean time between failure. All of the independent variables were statistically significant in the MAVLCC model.

The variation in MAVLCC's pipeline costs is explained mostly by the mean time between failure (48.4 %) and the depot cycle time (47.8 %). The least explanation is provided by the number of flying hours (3.8 %).

TABLE 16

Analysis of Variance Data

MAVLCC by Depot Cycle Time

SOURCE OF VARIATION	SUM OF SQUARES	DF	MEAN SQUARE	F	SIGNIF OF F
DEPOT CYCLE TIME	1.135	4	.284	26.576	.001
RESIDUAL	1.281	120	.011		
TOTAL	2.416	124	.019		

TABLE 17

ANALYSIS of Variance Data

MAVLCC by Flying Hours

SOURCE OF VARIATION	SUM OF SQUARES	DF	MEAN SQUARE	F	SIGNIF OF F
FLYING	.153	4	.038	2.030	.094
RESIDUAL	2.263	120	.019		
TOTAL	2.416	124	.019		

TABLE 18

Analysis of Variance Data

MAVLCC by MTBF

SOURCE OF VARIATION	SUM OF SQUARES	DF	MEAN SQUARE	F	SIGNIF OF F
MTBF	1.128	4	.282	26.272	.001
RESIDUAL	1.288	120	.011		
TOTAL	2.416	124	.019		

Analysis of the MAVMOD-A Model. The MAVMOD-A Model's analysis is shown in ANOVA tables 19-21, Table 19 shows MAVMOD-A by the depot cycle time, Table 20 is MAVMOD-A by the flying hours, and Table 21 is MAVMOD-A by the mean time between failure. All of the independent variables were statistically significant in the MAVMOD-A ANOVA model.

The variation in MAVMOD-A is explained mostly by the mean time between failure (44.0 %) and the depot cycle time (45.8 %). The least explanation is provided by the number of flying hours (10.2 %).

TABLE 19

Analysis of Variance Data

MAVMOD-A by Depot Cycle Time

SOURCE OF VARIATION	SUM OF SQUARES	DF	MEAN SQUARE	F	SIGNIF OF F
DEPOT CYCLE TIME	.479	4	.120	22.730	.001
RESIDUAL	.632	120	.005		
TOTAL	1.112	124	.009		

Interaction Effects. Two-way ANOVA's studied the effect of interactions among the independent variables, the depot cycle time, the number of flying hours, and the mean time between failure. All of the tests were performed at the .05 level, and there were not any statistically significant interactions. The experimental design is a 5^3 (five treatments of three factors) experiment was fashioned

TABLE 20

Analysis of Variance Data

MAVMOD-A by Flying Hours

SOURCE OF VARIATION	SUM OF SQUARES	DF	MEAN SQUARE	F	SIGNIF OF F
FLYING	.160	4	.040	5.026	.001
RESIDUAL	.952	120	.008		
TOTAL	1.112	124	.009		

TABLE 21

Analysis of Variance Data

MAVMOD-A by MTBF

SOURCE OF VARIATION	SUM OF SQUARES	DF	MEAN SQUARE	F	SIGNIF OF F
MTBF	.469	4	.117	21.882	.001
RESIDUAL	.643	120	.005		
TOTAL	1.112	124	.009		

to provide 125 factor levels of DEPOT, FLYING, and MTBF. This section examines first order interactions in a two factor ANOVA. The interactions were:

1. The depot cycle time with the number of flying hours
2. The number of flying hours with the mean time between failure.

3. The mean time between failure with the depot cycle time.

The results of the two-way interactions are shown in Tables 22-25. There were no statistically significant first order interactions for any of the ANOVA models. The effect of the independent variables acting together is not producing a statistically significant effect on the pipeline spare parts cost.

TABLE 22

Analysis of Variance Data

HCOM Interactions

SOURCE	SUM OF SQUARES	MEAN SQUARE	F-RATIO	F-SIGIF
DEPOT BY FLYING	0	0	.003	.999
FLYING BY MTBF	.002	0	.005	.999
MTBF BY DEPOT	0	0	.116	.999

TABLE 23

Analysis of Variance Data

MAVMOD Interactions

SOURCE	SUM OF SQUARES	MEAN SQUARE	F-RATIO	F-SIGNIF
DEPOT BY FLYING	0	0	0	.999
FLYING BY MTBF	0	0	0	.999
MTBF BY DEPOT	0	0	0	.999

TABLE 24

Analysis of Variance Data

MAVLCC Interactions

SOURCE	SUM OF SQUARES	MEAN SQUARE	F-RATIO	F-SIGNIF
DEPOT BY FLYING	0	0	0	.999
FLYING BY MTBF	0	0	0	.999
MTBF BY DEPOT	0	0	0	.999

TABLE 25

Analysis of Variance Data

MAVMOD-A Interactions

SOURCE	SUM OF SQUARES	MEAN SQUARE	F-RATIO	F-SIGNIF
DEPOT BY FLYING	0	0	.004	.999
FLYING BY MTBF	0	0	.003	.999
MTBF BY DEPOT	.001	0	.04	.999

The Tukey Tests

Introduction. The significance tests examined the effect of the independent variables upon pipeline cost computed by the different LCC models. This section analyzes differences among means of pipeline costs computed by each of the LCC models. Differences among group means were analyzed by Tukey's multiple comparisons procedure. A

multiple comparison, differs from a pairwise comparison in that it investigates all the group means in one experiment. The advantage in a multiple comparison comes from the application of one experimental confidence coefficient that is usually 95 percent. A problem with performing pairwise comparisons (T-Tests) between the four models is that confidence coefficient is significantly reduced because three different pairs of treatment means must be evaluated. Kleinbaum describes problems with performing several T-Tests:

> Unfortunately, there is a serious drawback to the approach of performing several such T-Tests; this drawback arises from the fact that the more null hypotheses there are to be tested, the more likely it is to reject one of them even if all null hypotheses are actually true [8:265].

The confidence coefficient that was applied to pairwise comparisons is now called an "experimental confidence coefficient". However there is a significant distinction between the pairwise and multiple confidence coefficients; with a multiple comparison, the confidence coefficient for any particular comparison is larger than the experimental confidence coefficient. Also, the pairwise confidence coefficient increases as the number of comparisons of population means increases (13:589-591).

The Tukey procedure was used for analyzing the group means. Tukey's procedure is available with SPSS. Neter and Wasserman suggest (13:473) that the Tukey method can be used

when all factor level sample sizes are equal and pairwise comparison of the means are of primary interest.

Group Means. The pipeline cost for each LCC model was calculated. Actual mean pipeline costs along with LOG_{10} transformations are shown in TABLE 26. This table provides a basis for comparing the pipeline costs computed by the four LCC models. LOG_{10} values were used for one-way ANOVA's and Tukey tests to increase the aptness of the ANOVA models.

TABLE 26

Average Pipeline Cost

Model	Mean	LOG_{10} of Mean
HCOM	$58,625,398	7.7069
MAVMOD	$118,341,748	8.0573
MAVLCC	$39,107,901	7.5701
MAVMOD	$51,731,318	7.7035

Significance Test. An alpha level of .05 was arbitrarily chosen for all of the hypothesis testing. To set up the appropriate null and alternate hypotheses, μ_1, μ_2, μ_3, and μ_4 denoted the mean costs for pipeline spare parts corresponding to the Hughes Cost of Ownership Model (HCOM), the MOD-METRIC Maverick Life Cycle Cost Model (MAVMOD), the Maverick Life Cycle Cost Model (MAVLCC), and

an updated MOD-METRIC Maverick (MAVMOD-A). The null hypothesis is that the average pipeline costs predicted by each model are equal at the $\alpha = .05$ level (.95 confidence coefficient).

$$H_o: \mu_1 = \mu_2 = \mu_3 = \mu_4$$

The alternate claim is that there are statistically significant differences in the pipeline costs, which can be stated by:

$$H_a: \mu_1 = \mu_2 = \mu_3 = \mu_4$$

Table 27 shows that the F-statistic is 226.627, which rejects the null hypothesis. There is a statistical difference in the means between the pipeline costs for the different models.

TABLE 27

Analysis of Variance Data

Pipeline Costs

SOURCE	D.F.	SUM OF SQUARES	MEAN SQUARE	F RATIO	F PROB
BETWEEN GROUPS	3	16.311	5.437	226.627	0
WITHIN GROUPS	496	11.900	.024		
TOTAL	499	28.211			

The Tukey Test Among Mean Pipeline Costs. The Tukeys multiple comparison tests determined that there were statistically significant differences among pipeline costs for the four LCC models. The Tukey Test determined that the four models could be classified into three subsets. The models within the groups are considered homogeneous, while models between different groups contain differences in the mean pipeline costs. The results are shown in Table 28, which arranges groups by their average value, ranging from lowest to highest pipeline costs. The first subset contains the Maverick Life Cycle Cost Model, which is considered different from all of the other models. The second subset contains the Modified MOD-METRIC Maverick and the Hughes Cost of Ownership Model. However, it should be noted that the standard deviation of pipeline costs between these two models are quite different; the standard deviation for HCOM is .23 and .14 for MAVLCC. The third subset contains the MOD-METRIC Maverick Life Cycle Cost Model, which mean value is different from the other three models.

Tukey Tests Among Factor Levels. Tukey's procedure of multiple comparisons was repeated for the factor levels of dependent variables. The results are shown for DEPOT in Table 29, for FLYING HOURS in Table 30, and for MTBF in Table 31. Each factor was tested for the five experimental levels. Tables 29-31 are formatted to show which models computed equal values of pipeline costs

Table 28

Tukey Model Classification

SUBSET	COMPONENTS	MEAN
1	MAVLCC	7.5701
2	MAVMOD-A	7.7035
	HCOM	7.7069
3	MAVMOD	8.0573

within a particular level. These models have been grouped in SUBSETs, which are a grouping of equal means by Tukey's procedure at a .05 confidence level. For example, in the groupings by DEPOT at level 1, The LCC models MAVLCC and HCOM are in the subset 1, MAVMOD-A is in subset 2, and MAVMOD is in subset 3.

The results shown by Tables 29-31 indicate that in nine of fifteen factor tests that the Hughes Cost of Ownership Model and the Modified MOD-METRIC Maverick were assigned to the same subset at the α = .05 level. Eight of these occurrences were observed with the factors DEPOT and FLYING HOURS. The Maverick Life Cycle Cost Model and the Hughes Cost of Ownership Model had equal means in four of fifteen occurrences. The MOD-METRIC Maverick did not have equal means with any of the other life cycle cost models. The results indicate that 1) each model computes the pipeline costs based on the Mean Time Between Failure differently.

2) HCOM and the Modified MOD-METRIC Model compute pipeline costs based on Flying Hours and Depot Cycle time similarly.
3) The Maverick Life Cycle Cost Model computes pipeline costs based on all three of the factors differently than each of the other different models.

TABLE 29

Tukey's Groupings

for Depot Levels

LEVEL	SUBSET 1	SUBSET 2	SUBSET 3
1	MAVLCC-HCOM	MAVMOD-A	MAVMOD
2	MAVLCC	HCOM-MAVMOD-A	MAVMOD
3	MAVLCC	HCOM-MAVMOD-A	MAVMOD
4	MAVLCC	HCOM-MAVMOD-A	MAVMOD
5	MAVLCC-MAVMOD-A	HCOM	MAVMOD

TABLE 30

Tukey's Groupings

for Flying Hours' Levels

LEVEL	SUBSET 1	SUBSET 2	SUBSET 3
1	MAVLCC-MAVMOD-A	HCOM	MAVMOD
2	MAVLCC	HCOM-MAVMOD-A	MAVMOD
3	MAVLCC	HCOM-MAVMOD-A	MAVMOD
4	MAVLCC	HCOM-MAVMOD-A	MAVMOD
5	MAVLCC-HCOM	HCOM-MAVMOD-A	MAVMOD

TABLE 31

TUKEY'S GROUPINGS

for MTBF Levels

LEVEL	SUBSET 1	SUBSET 2	SUBSET 3	SUBSET 4
1	MAVLCC	MAVMOD-A	HCOM	MAVMOD
2	MAVLCC	MAVMOD-A	HCOM	MAVMOD
3	MAVLCC	HCOM-MAVMOD-A	MAVMOD	
4	MAVLCC-HCOM	MAVMOD-A	MAVMOD	
5	MAVLCC-HCOM	MAVMOD-A	MAVMOD	

V. Summary of Findings, Conclusions, and Recommendations

Introduction

This study has addressed initial spare parts calculations in four life cycle cost models: the Hughes Cost of Ownership Model (HCOM), the Modified Metric Maverick (MAVMOD), the Maverick Life Cycle Cost Model (MAVLCC) and a version of the Modified Metric Maverick (MAVMOD-A). The primary research question was to determine if the four life cycle cost models compute equal numbers for pipeline spare parts. The secondary research question was to determine the effect that the independent variables (depot cycle time, flying hours, and mean time between failure) have upon the cost of pipeline spare parts for each life cycle cost model. This chapter summarizes the findings and presents conclusions derived from the research and recommends areas for further study.

Summary of Findings

The primary question was to determine whether or not each life cycle cost model computed equal pipeline costs. This was not supported. The differences in the costs computed by the models were observed because each life cycle cost model's structure is different; assumptions about the life cycle cost environment are different; and the

computational processes are different. The secondary question was to determine the effect that each of the independent variables had upon the life cycle cost models calculation of pipeline costs. The study determined that the most important variables were the mean time between failure (MTBF) and depot cycle time (DEPOT). The Number of Flying Hours (FLYING HOURS) had the least effect and was not statistically significant with the HCOM model. Presented is a review concerning the differences in the life cycle cost models and the effect of the independent variables upon those calculations.

Structural Differences. The literature review found that the structural design was different for each of the three models (MAVLCC, HCOM, MAVMOD). Major internal differences among the life cycle cost models are that MAVLCC does not include Shop Replaceable Units, HCOM does not use actual system data for determining updated monthly costs, and MAVMOD does not compute spares based on failure data.

Inspection of the MAVLCC program shows that it allows all of its independent variables to change from month to month, requiring all of the input data on a monthly basis. MAVLCC does not compute the cost of shop replaceable units (SRU) for pipeline costs. The lack of SRU calculations lowered MAVLCC's average pipeline costs by three million dollars. Inspection of the HCOM model showed that it does not update the system life cycle on a monthly basis; its

input data allows a direct calculation of peak requirements. Because monthly costs are not available, HCOM must determine program costs by averaging system information. Currently, this methodology does not provide results similar to the other models. The variance in pipeline cost is greatest for HCOM, and significantly affected by the mean time between failure as shown by the ANOVA results. Inspection of the MOD-METRIC Maverick shows that it is significantly different from both MAVLCC and HCOM. The cause of the differences are based on the input assumptions of the life cycle cost environment. Pipeline spares are allocated by the optimization routine, rather than failure data. The MOD-METRIC approach assumes that failures can be identified at base level, while MAVLCC and HCOM failures are based on system level. This results in "rounding" problems when comparing MAVMOD with MAVLCC and HCOM. During the conversion process, MAVMOD only allows integer failures and rounds partial failures up to the next highest integer. This has the effect of increasing MAVMOD's total requirement for spare parts.

Environmental Differences. MAVLCC and HCOM similarly define the concept of a pipeline, requiring that spare parts be stocked at the depot to account for failed parts at base level. Neither model requires a supply stock of base level parts. The MOD-METRIC approach is different. It generates two spare parts for each part that has failed in the field.

It replaces the failed part with a unit taken off the shelf from the base supply stock. Then, it replaces the base spare with a spare part from the depot supply stock. Although this conservative approach may be considered sound for the tactical missile (AGM), the expense for the training missile (TGM), which accounts for over 50 percent of MAVMOD's pipeline costs, should be questioned. There may not be an actual requirement to keep training spare parts 100 percent stocked. The spare parts supply are only one component necessary to keep the entire Maverick System capable of performing its mission. The model does not consider the total logistics system (which includes manpower and facilities) that is necessary for missile maintenance. In the MAVMOD-A model, a modification was made by removing the requirement to place spares at the depot (an assumption common to all the other models except MAVMOD), MAVMOD-A was able to produce pipeline cost estimates comparable to the other models. This is not to suggest that these are correct answers, but that the MAVMOD model has the flexibility to calculate cost based on different life cycle environments.

Computational Processes. A simplistic approach to spares calculations is provided by HCOM and MAVLCC. The process can be easily traced by failure rates and depot cycle time to the calculation of pipeline costs. This was indicated by the results of the ANOVA. HCOM was very sensitive to changes in the mean time between failure and

depot cycle time; MAVLCC was the next most sensitive model, and MAVMOD was the least sensitive. The operational usage factor, flying hours, had the greatest power in the MAVMOD model. The <u>power</u> is a description of the relative strength of the statistical significance (4:105). A complex optimizing calculation is provided in MAVMOD. The predictions of pipeline costs are an illusionary correlation. The costs are determined by optimizing an integer number of spares at each base, rather than by determination from the input factors. Thus, there is only a pseudo relationship between the independent variables and the calculation of pipeline cost.

<u>Independent Variable Effects</u>. The effects of the independent variables (depot, flying hours, mtbf) were examined by an Analysis of Variance (ANOVA). An ANOVA was performed for each model (HCOM, MAVMOD, MAVLCC, MAVMOD-A). The ANOVA indicated that the independent variables DEPOT and MTBF had the most significant effect on pipeline costs. Flying hours had the smallest effect and was not statistically significant in the HCOM model. In none of the ANOVA models were the interactions between any of the independent variables significant in affecting pipeline costs. Table 32 summarizes the percentage that each of the independent variables had upon pipeline costs for each life cycle cost model.

TABLE 32

EXPLAINED PERCENT VARIATION OF

INDEPENDENT VARIABLES

LCC MODEL	DEPOT	FLYING HOURS	MTBF
HCOM	19.9	.0	80.1
MAVMOD	46.4	6.7	46.9
MAVLCC	47.8	3.8	48.4
MAVMOD-A	45.8	10.2	44.0

Conclusions

The MOD-METRIC Maverick offers the greatest flexibility in calculating life cycle costs. It has the most options for simulating a variety of life cycle cost scenarios. MAVMOD has the capability of performing several different tasks such as spares determination, allocation, or distribution analysis. These functions are not directly supported by any of the other models. The determination of costs by base level allows the user to easily comprehend the effects of simulating input variables. HCOM and MAVLCC do not allow for pipeline costs by base level.

In this research, judgment was not made about the validity of any particular model, because actual cost data was not available. This study showed how each of the life cycle cost models performed given similar input conditions. The selection of a particular model depends upon the

assumptions that a decision maker makes about the life cycle environment and the relative importance of particular independent variables.

Recommendations

Several problems were identified during the course of this study. Brief description of the problems follow:

1. All of the models lacked the capability of computing pipeline spares as a function of time. This limitation prevents users from taking advantage of the time value of money, which would be very useful for preparing updates to the Program Objective Memorandum (POM). This information would enable decision makers to better prioritize the application of funds for different projects.

2. Managers lack confidence in life cycle cost models because of the absence of model verification tests. Models should be validated prior to Air Force acceptance. We should be provided with a validation certification prior to accepting life cycle cost models. This would assure the managers that there has been a formal consideration of the accuracy and reasonable detail of each model.

3. The determination of failure rates should be more consistent and automated. The method for determining the mean time between failure for components is done by analogy with provisioning conferences. For common parts, such as electronic components, this information should be accumulated into a data base available to logistics analyst.

4. Development of an ANOVA Residuals program. The Statistical Package for the Social Sciences (SPSS) does not provide residual analysis for ANOVA; neither do other major statistical packages. Although the residual computations are simple, they are tedious and require plotting packages. An ANOVA residual program would have aided this research significantly.

In the continuation of this research, I recommend an examination of the costs predicted by these models and the actual amounts procured for the Maverick. This information was not available during this research. As the virtual memory of the micro computer increases, I recommend that we move away from the small computer (VAX) and focus on the implementation of life cycle cost models in the micro computer. This would promote an added benefit of allowing more users access to the models (because there are large number of micro computers in the Air Force), which may spur improvements in life cycle cost model accuracy and capabilities.

TABLE 33

Data Base of

Independent and Dependent Variables

NUM	DEP	FLY	XMTBF	HCOM	AMAV	MAV	LMAV
1	1.07	1.05	.7	61,340,200	100,566,277	35,027,675	43,704,341
2	1.07	1.05	.85	42,497,122	85,167,349	28,846,321	38,961,711
3	1.07	1.05	1	30,704,171	74,037,814	24,519,373	35,206,556
4	1.07	1.05	1.15	23,216,765	67,352,485	21,321,194	33,456,336
5	1.07	1.05	1.3	18,168,150	61,993,908	18,861,056	31,300,286
6	1.07	1.27	.7	62,661,572	107,290,632	35,027,675	48,621,881
7	1.07	1.27	.85	42,497,122	91,686,372	28,846,321	41,140,641
8	1.07	1.27	1	30,704,171	79,866,836	24,519,373	37,251,861
9	1.07	1.27	1.15	23,216,765	71,653,521	21,321,194	34,618,131
10	1.07	1.27	1.3	18,168,150	65,173,226	18,861,056	32,872,386
11	1.07	1.5	.7	62,661,572	114,675,853	35,027,675	50,681,331
12	1.07	1.5	.85	42,497,122	97,636,974	28,846,321	45,226,536
13	1.07	1.5	1	30,704,171	85,861,800	24,519,373	39,283,021
14	1.07	1.5	1.15	23,216,765	76,123,830	21,321,194	36,925,971
15	1.07	1.5	1.3	18,168,150	69,391,989	18,861,056	33,575,121
16	1.07	1.72	.7	62,661,572	120,445,109	38,114,402	53,691,906
17	1.07	1.72	.85	42,497,122	102,880,027	31,388,331	47,138,216
18	1.07	1.72	1	30,704,171	90,993,375	26,680,081	42,527,841
19	1.07	1.72	1.15	23,216,765	81,618,115	23,200,071	38,235,536
20	1.07	1.72	1.3	18,168,150	73,149,578	20,523,139	36,599,841
21	1.07	1.95	.7	62,661,572	127,996,961	43,028,996	55,521,826
22	1.07	1.95	.85	42,497,122	108,471,078	35,435,644	49,216,526
23	1.07	1.95	1	30,704,171	95,627,145	30,120,297	44,922,156
24	1.07	1.95	1.15	23,216,765	86,456,105	26,191,563	41,332,586
25	1.07	1.95	1.3	18,168,150	78,241,148	23,169,460	37,187,811

(Continued)

NUM	DEP	FLY	XMTBF	HCOM	AMAV	MAV	LMAV
26	1.3	1.05	.7	75,769,144	117,603,072	42,565,161	51,530,503
27	1.3	1.05	.85	55,208,848	100,083,642	35,053,662	43,704,341
28	1.3	1.05	1	39,888,392	87,022,475	29,795,613	39,761,221
29	1.3	1.05	1.15	30,161,357	78,211,571	25,909,228	36,413,888
30	1.3	1.05	1.3	23,602,602	70,952,472	22,919,702	34,894,571
31	1.3	1.27	.7	81,404,884	126,004,867	42,565,161	54,159,063
32	1.3	1.27	.85	55,208,848	106,812,712	35,053,662	48,621,881
33	1.3	1.27	1	39,888,392	93,872,476	29,795,613	42,155,536
34	1.3	1.27	1.15	30,161,357	83,237,450	25,909,228	39,558,088
35	1.3	1.27	1.3	23,602,602	76,826,294	22,919,702	36,290,611
36	1.3	1.5	.7	81,404,884	135,001,486	42,565,161	56,696,433
37	1.3	1.5	.85	55,208,848	114,197,933	35,053,662	50,800,811
38	1.3	1.5	1	39,888,392	99,740,914	29,795,613	46,719,351
39	1.3	1.5	1.15	30,161,357	89,994,411	25,909,228	40,752,888
40	1.3	1.5	1.3	23,602,602	80,067,464	22,919,702	38,846,841
41	1.3	1.72	.7	81,404,884	143,174,387	46,307,217	61,035,433
42	1.3	1.72	.85	55,208,848	119,975,739	38,135,355	53,691,906
43	1.3	1.72	1	39,888,392	106,068,885	32,415,052	48,530,411
44	1.3	1.72	1.15	30,161,357	94,956,220	28,187,002	44,953,548
45	1.3	1.72	1.3	23,602,602	87,285,013	24,934,655	41,580,736
46	1.3	1.95	.7	81,404,884	150,703,592	52,278,220	64,151,343
47	1.3	1.95	.85	55,208,848	127,542,580	43,052,652	55,521,826
48	1.3	1.95	1	39,888,392	110,821,968	36,594,754	51,063,066
49	1.3	1.95	1.15	30,161,357	99,750,139	31,821,525	46,024,153
50	1.3	1.95	1.3	23,602,602	90,805,164	28,149,811	43,998,626

(Continued)

NUM	DEP	FLY	XMTBF	HCOM	AMAV	MAV	LMAV
51	1.53	1.05	.7	95,487,412	134,761,120	50,105,538	55,974,703
52	1.53	1.05	.85	69,242,994	114,978,823	41,263,384	49,857,783
53	1.53	1.05	1	50,028,066	100,681,042	35,073,876	43,704,341
54	1.53	1.05	1.15	37,828,405	88,841,352	30,499,023	40,592,866
55	1.53	1.05	1.3	29,602,408	80,211,529	26,979,905	36,663,476
56	1.53	1.27	.7	102,098,092	144,844,158	50,105,538	59,104,758
57	1.53	1.27	.85	69,242,994	123,009,612	41,263,384	52,849,498
58	1.53	1.27	1	50,028,066	107,410,112	35,073,876	48,621,881
59	1.53	1.27	1.15	37,828,405	96,206,701	30,499,023	44,430,371
60	1.53	1.27	1.3	29,602,408	85,437,908	26,979,905	40,151,971
61	1.53	1.5	.7	102,098,092	154,213,542	50,105,538	63,696,863
62	1.53	1.5	.85	69,242,994	129,728,701	41,263,384	55,740,593
63	1.53	1.5	1	50,028,066	114,795,333	35,073,876	50,800,811
64	1.53	1.5	1.15	37,828,405	101,966,850	30,499,023	47,201,986
65	1.53	1.5	1.3	29,602,408	93,325,669	26,979,905	43,143,686
66	1.53	1.72	.7	102,098,092	162,981,277	54,500,033	68,183,633
67	1.53	1.72	.85	69,242,994	138,943,112	44,882,380	59,835,918
68	1.53	1.72	1	50,028,066	120,573,139	38,150,023	53,691,906
69	1.53	1.72	1.15	37,828,405	108,493,088	33,173,933	48,888,851
70	1.53	1.72	1.3	29,602,408	97,375,320	29,346,171	45,671,626
71	1.53	1.95	.7	102,098,092	172,847,392	61,527,443	70,225,828
72	1.53	1.95	.85	69,242,994	147,042,980	50,669,659	63,123,173
73	1.53	1.95	1	50,028,066	128,259,460	43,069,210	55,521,826
74	1.53	1.95	1.15	37,828,405	113,283,504	37,451,487	51,302,026
75	1.53	1.95	1.3	29,602,408	103,337,619	33,130,162	47,248,441

(Continued)

NUM	DEP	FLY	XMTBF	HCOM	AMAV	MAV	LMAV
76	1.76	1.05	.7	117,155,572	150,747,418	57,648,806	61,548,978
77	1.76	1.05	.85	84,599,564	128,958,543	47,475,487	53,910,953
78	1.76	1.05	1	61,123,188	113,002,642	40,354,164	49,318,743
79	1.76	1.05	1.15	46,217,910	100,689,156	35,090,578	43,704,341
80	1.76	1.05	1.3	36,167,568	89,733,324	31,041,665	41,433,941
81	1.76	1.27	.7	124,741,200	163,291,534	57,648,806	66,279,423
82	1.76	1.27	.85	84,599,564	137,593,435	47,475,487	57,886,798
83	1.76	1.27	1	61,123,188	120,981,825	40,354,164	52,338,748
84	1.76	1.27	1.15	46,217,910	107,528,276	35,090,578	48,621,881
85	1.76	1.27	1.3	36,167,568	98,142,694	31,041,665	44,549,851
86	1.76	1.5	.7	124,741,200	173,100,279	57,648,806	70,857,383
87	1.76	1.5	.85	84,599,564	147,772,322	47,475,487	62,005,698
88	1.76	1.5	1	61,123,188	127,732,011	40,354,164	55,588,283
89	1.76	1.5	1.15	46,217,910	114,922,927	35,090,578	50,800,811
90	1.76	1.5	1.3	36,167,568	103,080,971	31,041,665	47,436,231
91	1.76	1.72	.7	124,741,200	184,572,222	62,692,848	73,295,738
92	1.76	1.72	.85	84,599,564	156,756,279	51,629,404	65,623,103
93	1.76	1.72	1	61,123,188	136,193,909	43,884,994	59,444,648
94	1.76	1.72	1.15	46,217,910	120,370,583	38,160,864	53,691,906
95	1.76	1.72	1.3	36,167,568	109,502,323	33,757,687	49,127,811
96	1.76	1.95	.7	124,741,200	195,302,227	70,776,667	78,236,853
97	1.76	1.95	.85	84,599,564	164,345,862	58,286,667	68,319,278
98	1.76	1.95	1	61,123,188	144,656,716	49,543,667	62,129,788
99	1.76	1.95	1.15	46,217,910	128,267,574	43,081,449	55,521,826
100	1.76	1.95	1.3	36,167,568	114,487,091	38,110,513	51,899,426

(Continued)

NUM	DEP	FLY	XMTBF	HCOM	AMAV	MAV	LMAV
101	1.99	1.05	.7	140,773,628	168,397,284	65,194,966	67,996,121
102	1.99	1.05	.85	101,278,556	142,653,834	53,689,972	59,196,643
103	1.99	1.05	1	73,173,764	124,630,633	45,636,476	53,381,343
104	1.99	1.05	1.15	55,329,874	111,378,283	39,683,893	48,079,033
105	1.99	1.05	1.3	43,298,086	100,694,959	35,104,982	43,704,341
106	1.99	1.27	.7	149,334,208	181,022,501	65,194,966	72,206,211
107	1.99	1.27	.85	101,278,556	153,356,756	53,689,972	64,060,713
108	1.99	1.27	1	73,173,764	132,706,657	45,636,476	56,902,843
109	1.99	1.27	1.15	55,329,874	118,254,282	39,683,893	50,965,413
110	1.99	1.27	1.3	43,298,086	107,534,079	35,104,982	48,621,881
111	1.99	1.5	.7	149,334,208	193,134,519	65,194,966	75,958,846
112	1.99	1.5	.85	101,278,556	163,955,468	53,689,972	67,764,593
113	1.99	1.5	1	73,173,764	142,485,685	45,636,476	61,274,848
114	1.99	1.5	1.15	55,329,874	125,408,592	39,683,893	54,458,623
115	1.99	1.5	1.3	43,298,086	114,928,730	35,104,982	50,800,811
116	1.99	1.72	.7	149,334,208	205,415,511	70,885,663	81,377,881
117	1.99	1.72	.85	101,278,556	172,554,296	58,376,429	70,819,208
118	1.99	1.72	1	73,173,764	151,827,245	49,619,964	64,156,513
119	1.99	1.72	1.15	55,329,874	134,062,262	43,147,795	56,761,748
120	1.99	1.72	1.3	43,298,086	120,348,096	38,169,203	53,691,906
121	1.99	1.95	.7	149,334,208	215,348,371	80,025,890	85,349,011
122	1.99	1.95	.85	101,278,556	183,498,967	65,903,674	75,052,873
123	1.99	1.95	1	73,173,764	158,669,145	56,018,123	67,211,128
124	1.99	1.95	1.15	55,329,874	141,821,971	48,711,412	60,641,688
125	1.99	1.95	1.3	43,298,086	128,278,516	43,090,864	55,521,826

Appendix B: HCOM Input Data

SYSTEM INPUT DATA

YEARS	10.00
TOTAL NUMBER OF ORG UNITS	103.00
OVERSEAS UNITS	33.00
SYSTEMS PER ORG UNIT	5.42
NUMBER OF DEPOTS	1.00
SMTBMA, HOURS	114.56
HOURS OF USE PER SYSTEM PER MONTH	9.36
ANNUAL DISCOUNT RATE	0.00
INVENTORY INTRODUCTION COST $	1200.00
ANNUAL COST PER ITEM MANAGED	9.87
ANNUAL RECURRING COST $	150.00
TRAINING COST PER CLASSROOM HOUR	0.00
TECHNICAL PUBLICATIONS COST PER PAGE,	$1986.30
TRAINING COST PER STUDENT, $ PER MONTH	
INTERMEDIATE:	0.00
DEPOT:	0.00
LABOR RATE, $ PER HOUR	
INTERMEDIATE:	30.68
DEPOT:	48.91
STUDENTS PER CLASS	
INTERMEDIATE:	0.00
DEPOT:	0.00
NUMBER OF TRAINING COURSES	
INTERMEDIATE:	0.00
DEPOT:	0.00
REPAIR TURNAROUND TIME DAYS	
INTERMEDIATE:	7.00
DEPOT:	14.00

FACTOR	CONUS	OVERSEAS
PIPELINE TIME, MONTHS (ONE WAY)		
HIGH VALUE	0.83	0.97
LOW VALUE	0.70	0.83
ORDER TIME, DAYS		
HIGH VALUE	31.00	76.00
LOW VALUE	8.00	12.00
PACKING FACTOR		
NON-EXPLOSIVE	1.94	1.94
CLASS A EXPLOSIVE	1.94	1.94
COST OF REPAIR SPACE $/SQFT/MO	0.00	0.00
COST OF INVENTORY STORAGE SPACE $/CUFT/MO	0.00	0.00
SHOPS	41.00	18.00

VALUES ASSUMED CONSTANT

QUANTITY PER SYSTEM	1.00	
NUMBER OF PECULIAR PARTS	0.00	
GSE MAINTENANCE COST -FRACTION OF GSE PRODUCTION COST		0.05
REVISIONS OF TECHNICAL PUBLICATIONS PER LIFE CYCLE		0.00
MANPOWER REQUIRED PER REPAIR ACTION		2.50
REPAIR TIME FRACTION TO MAKE A DISCARD DECISION		0.30
MAINTENANCE ACTIONS PER FAILURE		1.00
PART SALVAGE VALUE - PERCENT OF ITEM COST		0.00
ITEM SALVAGE VALUE - PERCENT OF ITEM COST		0.00
PERCENT OF MAINTENANCE ACTION NOT DONE AT IMA		0.98
PART STORAGE SPACE		0.00
ITEM STORAGE SPACE		0.00
PROBABILITY PART IS NON-EXPLOSIVE		1.00
STOCK PROTECTION LEVEL		0.90
FAILURE RATE PER CALENDER HOUR (NON-OPERATING)		0.000005509
MINIMUM NUMBER SPARES PER SHOP		0.00

MAVLCC INPUT DATA

Variable	Value	Description
AVGAM=	6.00000	R OF MISSILES ON ALERT PER AIRCRAFT
CL=	6.00000	NUMBER OF MISSILES PER LAUNCHER
ALUS=	0.00000	NUMBER OF AIRCRAFT ON ALERT "CONUS"
BLR=	24.51600	BASE LABOR RATE
DAA=	320.00000	DEPOT ACTIVE HOURS PER MONTH
DLR=	32.91800	DEPOT LABOR RATE
HF=	1.00000	HANDLING FACTOR
ICATO=	0.00000	OTHER OPS TEST(SEE OTHER FIRINGS PER MO)
ICATG=	1.50000	OTHER TGM TEST PER MONTH
ICATE=	36.00000	END MONTH FOR SPECIAL TEST
ICATS=	18.00000	START MONTH FOR SPECIAL TEST
LT=	12.00000	LEAD TIME IN MONTHS
MRF=	0.24000	BASE LEVEL "OFF-EQUIPMENT" PAPERWORK

(Continued)

Variable	Value	Description
MRO=	0.08000	BASE LEVEL "ON-EQUIPMENT" PAPERWORK
PEF=	0.94000	PERSONNEL EFFECTIVENESS (DEPOT)
PSC=	2.33100	PACKING AND SHIPPING (CONUS)
PSO=	3.17000	PACKING AND SHIPPING (OVERSEAS)
RPC=	115.00000	INVENTORY MANAGEMENT COST (CONSUMABLES)
SA=	10.89000	ANNUAL BASE INVENTORY MANAGEMENT COST
SHR=	1.50000	AVERAGE FLYING TIME IN HOURS PER MISSION
SMH(1)=	12.00000	PERIODIC CEI INSPECTION INTERVAL(MONTHS)
SMH(2)=	9999999	
SMH(3)=	9999999	
SR=	0.25000	MANHOURS PER SUPPLY RECORD TRANSACTION
TGMHR=	95.00000	TEST(TGM)MISSILE HRS./MONTH PER SQUADRON
TR=	0.16000 (RECORDS)	MANHOURS PER TRANSPORTATION TRANSACTION

(Continued)

Variable	Value	Description
AMED=	36.08000	MILITARY HEALTH COST PER MAN YEAR
ACF=	0.00000	ANALYSIS COST PER FIRING
AVGMOHR=	720.00000	AVERAGE AVAILABLE MANHOURS PER MONTH
ALINSP(1)=	1.50000	ALERT INSPECTION INTERVAL IN MONTHS
ALINSP(2)=	999999	(PER CEI)
ALINSP(3)=	1.50000	
BMR=	4.77000	BASE MATERIAL RATE/MANHOUR CONSUMABLES
BMRC=	0.01000	FRACTION OF UNIT COST (BASE MATERIAL)
CACMR=	0.00000	ACM RANGE COST PER HOUR
DMR=	15.12500	DEPOT MATERIAL PER MANHOUR (CONSUMABLES)
DMRC=	0.01000	FRACTION OF UNIT COST (DEPOT MATERIAL)
FADM=	0.00000	MONTHLY O & M COSTS NEW DEPOT FACILITIES
FOLM=	0.00000	MONTHLY O & M COSTS NEW BASE FACILITIES
IMC=	51.30000	INITIAL INVENTORY MANAGEMENT COST/ITEM
LAUPAC=	2.00000	NUMBER OF LAUNCHERS PER AIRCRAFT

(Continued)

Variable	Value	Description
NUMINSP(1)=	2.00000	MANPOWER PER CEI REQUIRED FOR INSPECTION
NUMINSP(2)=	2.00000	(RECEIVING OR PERIODIC)
NUMINSP(3)=	1.00000	
PCSC=	1300	MILITARY PCS COST PER YEAR (CONUS)
PCSO=	2522	MILITARY PCS COST PER YEAR (OVERSEAS)
PERSUPC=	618	MILITARY PERSONNEL SUPPORT COST PER YEAR
PMBAMN=	1728	AVAILABLE WORK-HOURS PER YEAR (BASE)
RCFIRE=	0.00000	TEST RANGE COST PER EACH FIRING
SIMH=	1000	EQUIVALENT LINES OF SOFTWARE PER SYSTEM
SQUAD=	1.78000	NUMBER OF SQUADRONS PER BASE
TD=	0.11000	AVERAGE COST PER PAGE OF DOCUMENTATION
TDP	1380.00000	TOTAL NUMBER OF PAGES PER DOCUMENT SET
TNGMIL=	633.00000	MILITARY PERSONNEL TRAINING COST PER YR.
TDPPER=	0.05000	FRACTION OF DOC. PAGES REVISED PER YEAR
TRANIND=	1.00000	RECEIVING LOC. TO BASE TRANSPORT FACTOR
TORA=	0.10000	FRACTION OF MILITARY SEPARATIONS PER YR.

Appendix D

Baseline Failure Rates

(HOURS)

I	LRU/SRU	OPERATIONAL	STORAGE	ALERT
1	AGM Forward Section	84	172,117	26,840
2	AGM Aft Section	14,000	960,000	420,000
3	AGM Hydraulic Actuation System	910	864,000	240,000
4	TGM Forward Section	84	172,117	100,000,000
5	TGM Recorder	344	390,000	100,000,000
6	TGM Signal Processor	1,210	2,800,000	100,000,000
7	TGM AFt Section	14,000	6,700,000	100,000,000
8	Launcher Electrical System	166	478,000	120,000
9	Launcher Mechanical System	25,000	1,065,000,000	35,500,000

Bibliography

1. Banks, Jerry and John S. Carson. Discrete-Event System Simulation. Englewood Cliffs NJ: Prentice-Hall, 1984.

2. Blake, Major Robert T. Multi-Echelon Stockage Analysis Study. US Army Concepts Analysis Agency. Department of the Army, 1984.

3. Department of the Air Force. "AFLC Cost and Planning Factors", AFLC 173-10, 31 December 1981.

4. Devore, Jay L. Probability & Statistics for Engineering and the Sciences, Monterey: Brooks/Cole, 1982.

5. Hughes Aircraft Company, Missile Systems Group, Laser Maverick Production Program. Life Cycle Cost Estimate Document-HAC Reference E9482, 17 October 1984.

6. Hughes Aircraft Company. Users Manual for the Cost of Ownership Model. February 1977.

7. Kirk, Roger E. Experimental Design: Procedures for the Behavioral Sciences. Belmont CA: Wadsworth Publishing, Inc., 1968.

8. Kleinbaum, David G. and Lawrence L. Kupper. Applied Regression Analysis and Other Multivariable Methods. Belmont CA: Wadsworth Publishing Company, 1978.

9. Law, Averill M. and W. David Kelton. Simulation Modeling and Analysis. New York: McGraw-Hill, 1982.

10. McNickols, Lt Col Charles W. An Introduction to Applied Multivariate Analysis. Classroom Notes. School of Engineering, Air Force Institute of Technology (AU), Wright-Patterson AFB OH.

11. Muckstadt, John A. "A Model for a Multi-item, Multi-echelon, Multi-indenture Inventory System," Management Science, 20: 472-481 (December 1974).

12. Muckstadt, Capt John A. An Algorithm for Determining Optimum Stock Levels in a Multi-echelon Inventory System. LS Technical Report, SLTR 13-71. School of Systems and Logistics, Air Force Institute of Technology, Wright-Patterson AFB OH April 1971 (AD A042664).

13. Neter, John and William Wasserman. Applied Linear Stastical Models. Homewood Hills IL: Irwin, 1974.

14. Nie, Norman H. and others. SPSS: Statistical Package for the Social Sciences. New York: McGraw-Hill, 1975.

15. Shannon, Robert E. Systems Simulation the Art and Science, Englewood Cliffs NJ: Prentice-Hall, 1975.

16. Sherbrooke, Craig C. "Metric: A Multi-Echelon Technique for Recoverable Item Control," Operations Research, 16: 122-141 (1968).

17. Ultrasystems Defense & Space Systems, Inc. User's Manual for the Maverick Weapon System Life Cycle Cost (MAVLCC) Model, 15 June 1984.

18. Van Horn, Richard L. "Validation of Simulation Results," Management Science 17: 247-258 (1971).

VITA

Captain Lloyd A. Greene was born on 4 June 1956 in Cambridge, Massachusetts. He graduated from high school in Naugatuck, Connecticut, in 1974 and attended Northeastern University from which he received the degree of Bachelor of Science in Chemical Engineering in June 1980. Upon graduation, he received a commission in the USAF through the ROTC program. He served as a test engineer with the Airborne Laser Laboratory, Kirtland AFB, New Mexico, until entering the School of Logistics, Air Force Institute of Technology, in June 1984.

Permanent address: 49 Snow Crystal Road
Naugatuck, Connecticut 06770

UNCLASSIFIED

SECURITY CLASSIFICATION OF THIS PAGE

AD-A162 283

REPORT DOCUMENTATION PAGE

1a. REPORT SECURITY CLASSIFICATION UNCLASSIFIED	1b. RESTRICTIVE MARKINGS
2a. SECURITY CLASSIFICATION AUTHORITY	3. DISTRIBUTION/AVAILABILITY OF REPORT Approved for public release; distribution unlimited.
2b. DECLASSIFICATION/DOWNGRADING SCHEDULE	
4. PERFORMING ORGANIZATION REPORT NUMBER(S) AFIT/GSM/LSY/85S-15	5. MONITORING ORGANIZATION REPORT NUMBER(S)
6a. NAME OF PERFORMING ORGANIZATION School of Systems and Logistics 6b. OFFICE SYMBOL (If applicable) AFIT/LSY	7a. NAME OF MONITORING ORGANIZATION
6c. ADDRESS (City, State and ZIP Code) Air Force Institute of Technology Wright-Patterson AFB, Ohio 45433	7b. ADDRESS (City, State and ZIP Code)
8a. NAME OF FUNDING/SPONSORING ORGANIZATION 8b. OFFICE SYMBOL (If applicable)	9. PROCUREMENT INSTRUMENT IDENTIFICATION NUMBER
8c. ADDRESS (City, State and ZIP Code)	10. SOURCE OF FUNDING NOS. PROGRAM ELEMENT NO. / PROJECT NO. / TASK NO. / WORK UNIT NO.
11. TITLE (Include Security Classification) See Box 19	
12. PERSONAL AUTHOR(S) Lloyd A. Greene, B.S., Captain, USAF	

13a. TYPE OF REPORT	13b. TIME COVERED	14. DATE OF REPORT (Yr., Mo., Day)	15. PAGE COUNT
MS Thesis	FROM ______ TO ______	1985 September	135

16. SUPPLEMENTARY NOTATION

17. COSATI CODES			18. SUBJECT TERMS (Continue on reverse if necessary and identify by block number)
FIELD	GROUP	SUB. GR.	

19. ABSTRACT (Continue on reverse if necessary and identify by block number)

Title: EVALUATION OF SPARING MODELS FOR A MISSILE SYSTEM

Thesis Chairman: Jeffrey J. Phillips, Lt Col, USAF
Instructor in Acquisition Management

Approved for public release: IAW AFR 190-17.
Lynn E. Wolaver 11 Sept 85
LYNN E. WOLAVER
Dean for Research and Professional Development
Air Force Institute of Technology (ATC)
Wright-Patterson AFB OH 45433

20. DISTRIBUTION/AVAILABILITY OF ABSTRACT	21. ABSTRACT SECURITY CLASSIFICATION
UNCLASSIFIED/UNLIMITED ☒ SAME AS RPT. ☐ DTIC USERS ☐	UNCLASSIFIED

22a. NAME OF RESPONSIBLE INDIVIDUAL	22b. TELEPHONE NUMBER (Include Area Code)	22c. OFFICE SYMBOL
Jeffrey J. Phillips, Lt Col, USAF	513-255-4845	AFIT/LSY

DD FORM 1473, 83 APR EDITION OF 1 JAN 73 IS OBSOLETE.

UNCLASSIFIED

SECURITY CLASSIFICATION OF THIS PAGE

This study investigated pipeline spares calculation with four life cycle cost models for the Maverick Missile System. The research goal was to evaluate any differences in the pipeline costs that were calculated by the Hughes Cost of Ownership Model, the Maverick Life Cycle Cost Model, and the Modified METRIC Maverick Model, and a variation of the Modified METRIC Maverick.

The analysis was accomplished by identifying the independent variables with a Factor Analysis. A Factorial Design of three factors and five levels was used to develop the observations that were used by the life cycle costs models to calculate pipeline costs. The relative affect that each of the independent variables had upon the pipeline costs was evaluated by an Analysis of Variance. Differences in life cycle cost models pipeline costs were determined by Tukey's procedure. The results indicated that costs produced by the Hughes Cost of Ownership Model and the Modified MOD-METRIC Maverick calculated equal pipeline costs, but the Maverick Life Cycle Cost Model and the MOD-METRIC Maverick did not compute costs equal to any other life cycle cost model. The independent variables of Mean time Between Failure and the Depot Cycle Time had the most effect upon each of the life cycle costs models pipeline costs.

END

FILMED

1-86

DTIC